CSIRO Land and Water

Systematic Regional Planning for Multiple Objective Natural Resource Management

A Case Study in the South Australian River Murray Corridor

Brett Bryan[1], Neville Crossman[2], Tiffany Schultz[3], Jeff Connor[1] & John Ward[1]

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Stage 2 Report for the River Murray Dryland Corridor Project

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Acronyms

ALUMC – Australian Land Use and Mapping Classification

DEH – South Australian Department of Environment and Heritage

DWLBC – Department of Water, Land and Biodiversity Conservation

EAE – Equal Annual Equivalent

EC – Electrical Conductivity units (µS/cm)

EPBC – Environmental Protection and Biodiversity Conservation

GAMS – General Algebraic Modelling System

GIS – Geographic Information Systems

GM – Gross Margin

INRM – Integrated Natural Resource Management

ITP – Integrated Tree Processing

LAP – Local Action Planning

LSCP – Location Set Covering Problem

LTE – Long-Term Eroding

MADM – Multiple Attribute Decision Making

MCDA – Multi-Criteria Decision Analysis

MCLP – Maximal Covering Location Problem

MDD – Murray-Darling Depression

MIRR – Modified Internal Rate of Return

ML – Megalitre (10^6 litres)

MODM – Multiple Objective Decision Making

MW – Megawatt (10^6 Watts)

NAP - National Action Plan for Salinity and Water Quality

NHT – Natural Heritage Trust

NPV – Net Present Value

NPWS – National Parks and Wildlife Service

NRM – Natural Resource Management

PIRSA – Department of Primary Industries and Resources of South Australia

RCT – Resource Condition Target

RMCWMB – River Murray Catchment Water Management Board

SA MDB – South Australian Murray-Darling Basin

SCP – Systematic Conservation Planning

SLS – Soil Land System

SRP – Systematic Regional Planning

UNESCO – United Nations Educational, Scientific and Cultural Organisation

Executive Summary

Introduction

Agricultural production has facilitated the economic and social development of many regions in Australia and elsewhere, often at the significant public cost of widespread land, water and biological degradation. To ensure the sustainability of the environmental, economic and social systems in these regions, complex decisions have to be made about the nature and location of the natural resource management actions required to mitigate and reverse multiple natural resource management objectives. The concept of systematic regional planning (SRP) for natural resource management (NRM) as developed in the context of the South Australian River Murray Corridor (the *Corridor*) provides a structured and quantitative approach to the analysis of complex natural resource management decisions.

In the Corridor, the large scale clearance of deep-rooted native vegetation for agriculture and the grazing of remnant vegetation by livestock have led to the degradation of the native biodiversity, an increase in groundwater recharge and river salinity, and increased soil wind erosion (INRM Group 2003a). Regional targets have been set to address these multiple natural resource management objectives (INRM Group 2003c). Carbon sequestration is also discussed as another NRM objective in the Corridor.

The aim of this study is to assess the feasibility of different policy options for encouraging the large scale NRM actions required for achieving stated regional resource condition targets for NRM. To achieve this, the concept of systematic regional planning is developed to identify geographic priorities for NRM actions that most cost effectively meet multiple-objective regional targets based on established biophysical and economic principles. Systematic regional planning also involves the estimation of the cost of meeting regional targets and suggests policy instruments, especially market-based instruments that will provide the greatest chance that the targets will be met.

In this study we concentrate on three main NRM actions – vegetation management, revegetation of local native species and revegetation of biomass species. Note that the term *vegetation management* involves managing vegetation for biodiversity conservation values. Biomass provides a market-based incentive for encouraging large scale revegetation with associated NRM benefits. Fodder crops are also discussed as a potential NRM action.

For the purposes of this study, these three NRM actions address NRM objectives of salinity, biodiversity, wind erosion and carbon sequestration. Vegetation management and revegetation of local native species can address all four NRM objectives of biodiversity, salinity, wind erosion and carbon sequestration. Biomass can address salinity, wind erosion and carbon. Fodder are considered to address salinity and wind erosion targets only.

Systematic regional planning is a process based on decision theory and implemented within a spatial Multi-Criteria Decision Analysis framework. The MCDA framework involves 7 stages including problem definition, assembly of the evaluation criteria data layers, identification of the decision variables, specification of the criterion weights, formulation of the decision rules, conducting sensitivity analysis, and making recommendations:

1. The decision problem involves the selection of geographic priority locations for vegetation management and revegetation of local native species and biomass that most cost effectively achieve multiple natural resource management objectives.
2. Assembly of evaluation criteria data layers includes using a variety of spatial modelling techniques based on established biophysical and planning principles to create a series of GIS layers. The foundation data structure is based on raster GIS where the Corridor study area is tessellated into 188,655 x 254 m resolution (approximately 6.5 ha) grid cells. Creation of each of these layers involves distinct

GIS-based methods and the results of these individual analyses have policy implications. The analyses include the quantification of the spatial distribution of:

- Salinity benefit to the River Murray achieved through revegetation using the SIMPACT salinity model
- Biodiversity priorities for both vegetation management and revegetation using established systematic conservation planning principles including costing these actions
- Opportunity costs of agriculture based on land use data
- Economic viability of biomass production including a full sensitivity analysis
- Soil wind erosion potential and long term eroding areas

3. The decision variables are grid cells and the decision to be made is which grid cells should be subject to which NRM action to most cost effectively reach regional NRM targets
4. Criterion weights are not used to manipulate the influence of specific attributes but weights are incorporated into the models for future modification
5. The decision rules use spatial optimisation to identify geographic priorities for the NRM actions of vegetation management and revegetation of local native species such that resource condition targets are met at minimum cost. Decision rules for biomass aim to identify cells for biomass production that meet production and NRM targets and maximise the economic returns.
6. Outputs from MCDA quantify the spatial distribution of priority NRM actions in the Corridor. Multiple models of increasing planning sophistication provide flexibility for the decision maker and quantify the costs of meeting NRM targets in the Corridor. Outputs are used to assess and discuss the feasibility of meeting resource condition targets
7. Policy options for encouraging large scale NRM actions in the Corridor are outlined and the best options are discussed in the context of the economic, environmental, social, and institutional outcomes.

Preliminary Analyses and Assembly of Evaluation Criteria Layers

A number of analyses are conducted to provide essential input into the spatial MCDA in systematic regional planning. Many of these analyses involve the creation of spatial data layers used later as attributes in MCDA. These are described below:

Salinity

Methods

The quantity and costs of salinity benefit to the River Murray achieved through revegetation of deep rooted perennials are calculated based on the latest model outputs from SIMPACT that characterise the total salinity benefit for the River Murray from revegetating dryland areas in kg/ha/yr. These are converted to units of Electrical Conductivity (EC) at Morgan (µS/cm) and the costs of salinity to downstream users avoided by revegetation is calculated at a flow rate of 10,000 ML/day using the Murray-Darling Basin Commission's (MDBC) Ready Reckoner. Avoided costs are calculated in present value terms over a timeframe of 100 years using a discount rate of 3%. The magnitude of the effect of revegetation in dryland areas on river salinity levels is reassessed and geographic priorities are identified for revegetation to contribute to salinity resource condition targets for NRM.

Key Findings

- The total salinity contribution from the dryland areas of the Corridor in 100 years has been estimated to be around 30 EC at Morgan (Barnett and Yan 2004). However, the salinity benefits achieved through revegetation as modelled by SIMPACT over a 100 year time frame is 1.96 EC at Morgan after 50 years and 4.14 EC at Morgan. This is considered to be a conservative estimate and research is required to improve this estimate.
- Based on these estimates the total cost to downstream users of river salinity avoided by revegetation in the dryland areas of the Corridor is just over $3.15 Million in present value terms over 100 years.
- Most of the salinity benefits can be achieved by revegetating an area of 10,000 ha.

Policy Implications

The modelled river salinity benefits and the associated costs to downstream users avoided by revegetation in the dryland areas of the Corridor are low. They also occur well into the future and hence, are heavily discounted in economic analyses. Conversely, the costs involved in revegetation and the opportunity costs are high and immediate. Hence, based on these estimates, the implementation of a scheme that encourages revegetation for salinity alone is not a cost effective policy option for the Corridor. The integration of salinity credits into integrated NRM policies could however, complement other incentives for landholders to undertake NRM actions. The cost of salinity to downstream users may provide a suitable guide as to the appropriate level of payment for salinity credits in the Corridor.

Salinity mitigation has potential to be an economic driver of NRM actions in the Corridor. More accurate estimates of the salinity benefit of revegetation are required. Revegetation policy for salinity benefits needs to be specifically targeted to encourage revegetation in the high salinity benefit areas.

Biodiversity

The conservation of biodiversity is a high priority in regional NRM (Kahrimanis *et al*. 2001). Resource condition targets specified for terrestrial biodiversity in the Investment Strategy (INRM Group 2000c) specify that 50% of remnant vegetation on private land should be managed and that the area of native vegetation should be increased by 1%. However, if these large scale NRM actions are not targeted in high priority biodiversity areas they will not be maximally effective at conserving biodiversity. Targeting high priority areas needs planning.

Systematic conservation planning principles (Margules and Pressey 2000) underlie geographic priority setting for both vegetation management and revegetation for biodiversity. A series of data layers have been created for setting geographic priorities for both remnant vegetation management and revegetation for biodiversity for input into MCDA including a suite of layers produced by Crossman *et al*. (2004):

Vegetation Management	Revegetation
Patch Area Patch Shape Fragmentation Habitat Quality Vegetation Communities Climate Zones Rare and Threatened Species Habitat	Landscape Context Fragmentation Pre-European Vegetation Communities Climate Zones Soil Land Systems

Costs of Vegetation Management and Revegetation for Biodiversity

The cost of undertaking NRM actions is highly variable from one location to another due to the heterogeneous nature of the physical and biological environments of the Corridor. The NRM actions of vegetation management and revegetation have three major components – fencing, revegetation and weed management. Fencing costs vary according to the types of fence required and the substrate. Revegetation costs vary according to the method used which include tube stock planting, direct seeding and natural regeneration. Weed management costs vary according to the level of disturbance of the vegetation and the level of infestation. Low and high estimates of the average cost for both vegetation management and revegetation are put at $500 - $3,000 per hectare in the Corridor. These figures are used to estimate the total costs of meeting regional resource condition targets.

Carbon

Assessment of the economic potential of carbon trading in this study was limited to initial estimates based on indicative figures because at the time when the research was conducted the carbon market was not sufficiently developed to justify a full analysis. By the time of writing the report, the price of carbon on the European market had doubled and higher estimates of carbon productivity in the Corridor were published (Hobbs and Bennell 2005). We now consider that carbon trading has considerable potential as an economic driver of large scale NRM.

Key Findings

- Given recent empirical productivity estimates (Hobbs and Bennell 2005), trading the carbon produced by revegetation in the Corridor could produce annual returns between $50 and $105 per hectare which is comparable to current agriculture.
- It is possible that vegetation management activities could attract carbon credits.
- Revegetation of local native species for biodiversity is ideally suited for carbon trading and the restored native community not only has multiple NRM benefits but an income may also be generated from carbon trading.
- Revegetation of fodder crops such as saltbush is unlikely to attract substantial carbon credits because of the low productivity of the species.
- Biomass species are also suited for attracting carbon credits and there may be 2 options for carbon accounting of biomass species. Although they are harvested periodically and burned, the carbon stored in the woody lignotuber may be counted. The other option is that the carbon emissions avoided by producing clean electricity may be counted. This is around $1,375,000 per annum in carbon credits at current prices from a single 5MW ITP plant.

Policy Implications

The carbon market is developing rapidly. Initial estimates suggest that current carbon trading prices are sufficient to provide farmers a viable income source to support revegetation and possibly vegetation management in the Corridor. Market-based policy may involve either integrating carbon credits within other NRM schemes or creating a stand alone carbon program similar to the Victorian CarbonTender program.

Although the current economic returns from carbon trading in the Corridor may potentially be economically viable, barriers to trade from Australia's non-participation in the Kyoto protocol and market uncertainty obstruct the widespread land use change in the Corridor. If these can be overcome, carbon trading has the potential to provide additional incentives for participation in other programs such as biomass production. Carbon trading may also have the potential to become a stand alone economic driver for widespread land use change. Carbon provides an ideal incentive for encouraging the revegetation and restoration of native habitat which has NRM benefits for biodiversity, salinity and wind erosion.

Any stand alone carbon trading program needs to offset both the cash flow problem and the uncertainty involved in the carbon market. This can be done by tendering for carbon contracts where the government pays the landholder upfront for the first few years carbon production which may be paid back by the landholder from selling the carbon at a later date on the market. After that the landholder is free to trade the carbon on the open market. This involves some risk to both parties and speculation on the price of carbon.

Opportunity Costs

Opportunity costs are the cost of foregone income from agricultural land uses such as grazing and cereal cropping and are calculated based on the current value of agricultural production. The spatial distribution of dryland agriculture was quantified and mapped using catchment scale land use and based on average gross margin figures for 5 categories of dryland land use: Cereals; Grazing; Hay & Silage; Legumes; and Other Minimal Use. Gross margin figures were adjusted according to rainfall as modelled using BIOCLIM.

Opportunity costs of dryland agriculture as modelled in this study range from $7.83/ha to $199.00 per hectare with a mean of $46.53 and the total opportunity costs to agriculture in the Corridor is $29.25 Million per year. A layer of opportunity costs is used as an attribute in the MCDA to identify the least expensive locations for NRM actions.

Biomass

Biomass production involves monoculture plantings of *E. oleosa* harvested initially after a 6-year establishment period followed by three-yearly harvests. In full production, the ITP plant needs a constant supply of 100,000 green tonnes of biomass each year. The crops require minimal annual maintenance and fertilisation following harvest. Economic returns to biomass production depend on the production of the site and the price per tonne of biomass. The costs of biomass production include establishment costs, maintenance costs, harvest costs, fertiliser costs, opportunity costs, and transport costs. Different costs occur at different times in the production schedule. The location selected for establishment of the ITP is Kingston-on-Murray because of the plentiful supply of land nearby and the situation in the heart of the areas providing the greatest salinity benefits from revegetation.

Economic models are built in GIS using layers describing biomass productivity, opportunity costs, travel costs and the scalar parameters of harvest costs, maintenance costs and fertiliser costs. The economic measures of Net Present Value (NPV), Modified Internal Rate of Return (MIRR) and Equal Annual Equivalent (EAE) are calculated to quantify the costs and returns to biomass occurring at irregular intervals using discounting to account for time preference. The economic assessment is conducted in two phases. First, the Most Likely Scenario performs a single analysis of the profitability of biomass production using the most likely parameter values over a 100 year time period. The biomass productivity and Net Present Value layers from the Most Likely Scenario are used as attributes in MCDA. Second, a sensitivity analysis conducted using Monte Carlo techniques quantifies the effects of parameter uncertainty on the economic potential of biomass. The risk layer from the sensitivity analysis is used as an attribute in MCDA.

Key Findings

- Biomass production for supplying an Integrated Tree Processing (ITP) plant is very likely to be as profitable as, or more profitable than, existing agriculture in the Corridor. Under the Most Likely Scenario (time frame of 100 years and discount rate of 7%) the total net present value of biomass production for each 6.4 ha grid cell ranges between $5,000 less, to $25,000 more, than returns from existing agriculture with an average NPV of $7,168. The Modified Internal Rate of Return ranges between 6.8% and 7.7% and the Equal Annual Equivalent payments range from -$54 to $271 per year per grid cell or -$8.37/ha/yr to $42/ha/yr. The total potentially viable area for biomass production is 625,231 ha or 99.6% of the dryland area of the Corridor. The potential tonnage of green biomass supplied by the economically viable area (490 million tonnes per annum) far exceeds the production required to supply an ITP plant (100,000 tonnes per annum).

- The most profitable locations for biomass production were found to be interspersed with existing irrigation areas. Biomass production in these areas may also have synergistic salinity benefits in lowering water tables and reducing recharge whilst at the same time increasing biomass production through soil water mining. The synergies between biomass and irrigation in the Corridor should be investigated further.
- Cash flow is a problem for production of biomass as farmers do not register a positive cash flow for at least 7 years. Biomass production may take much longer than this to return a positive net cash flow for the farmer depending on site characteristics.
- Sensitivity analysis shows that no parts of the Corridor are profitable under all possible parameter values. Under average conditions many parts of the Corridor are viable for biomass production but some are not. An optimistic view of biomass production which assumes low costs and high prices and productivities would state that all areas have the potential to be viable and some areas have the potential to be considerably more profitable than existing agriculture.
- The factory gate price of biomass is the single most important factor affecting the profitability of biomass production in the Corridor.
- Conservatively, a robust supply of >100,000 tonnes of biomass per year can be expected when the factory gate price of biomass exceeds $35 per green tonne. At this price biomass production becomes more profitable than current agriculture over a large enough area to produce a supply of > 100,000 tonnes.

Policy Implications

Biomass production is probably viable as a stand alone economic exercise in the Corridor. However, establishment of a viable biomass industry involves much more than demonstrating its potential viability. To achieve a viable biomass industry in the Corridor, an Integrated Tree Processing plant has to be established and landholders have to be contracted to grow biomass. These steps will require significant industry development initiative to be taken, either by the SA government or other relevant agencies such as the Regional Development Board. There are several ways forward for establishing a biomass industry including private contractual arrangements with the commercial sector (e.g. energy companies) and landholders, farmers co-operatives and other models.

Carbon sequestration and trading also looms as another potential driver of a biomass industry in the Corridor and elsewhere in SA for that matter. In addition, the additional income generated from a potential involvement in carbon trading would significantly increase the profitability of biomass. An issue to be overcome however, is the cash flow problem. Contractual arrangements may need to be established that provide a regular payment to landholders such as the Equal Annual Equivalent payment.

Based on recent modelling, the salinity and wind erosion benefits of biomass in particular mitigation, have been shown to be somewhat less than expected. However, the NRM benefits are significant and may justify the effort and expenditure required to establish a biomass industry. The larger the area of biomass production the greater the NRM benefits. Market research is required to quantify the market for biomass products such as renewable energy. Economies of scale may quickly be achieved for NRM benefits if the market for biomass products would support more than one ITP plant in the Corridor. Once the initial industry development work has been done the industry should prove to be viable on its own and contribute significant public NRM benefits. For a single plant the cost-benefit of establishing a biomass industry is fairly equivocal but for more than one plant the NRM benefits may justify industry development if the market is there for the ITP products.

Wind Erosion

Wind erosion layers include both long-term eroding lands and wind erosion potential of soil landscape units as mapped by DWLBC.

Key Findings

- The total area of long-term eroding land in the Corridor is 312 ha.
- The total area of soils with a wind erosion potential of moderately high to high is 40,000 hectares or 4% of the study area.

Policy Implications

Wind erosion is a significant NRM problem in the Corridor with substantial public costs. However, public wind erosion benefits do not provide sufficient incentive to drive private investment in NRM actions. Wind erosion benefits could be integrated into a broader public NRM policy in the Corridor. Policy incentives for addressing wind erosion would also need to be specifically targeted at high priority sites.

Decision Rules for Systematic Regional Planning

The decision rules used in this study for prioritising grid cells for NRM actions that most cost-effectively meet resource condition targets are based on spatial optimisation using integer programming. Spatial optimisation models select grid cells for particular types of NRM action that minimise or maximise an objective function whilst satisfying certain targets/constraints. Spatial optimisation models select the optimal set of grid cells for vegetation management, revegetation for biodiversity, and revegetation for biomass. Models are built in GAMS.

Remnant Vegetation Management

A number of layers are used to set geographic priorities for vegetation management. The layers are either used as a cost in the objective function, or as a constraint in the optimisation model. In addition to the vegetation management attributes, we integrate opportunity costs and other NRM attributes into the vegetation management model. The overarching resource condition target affecting remnant vegetation management is that 50% of remnant vegetation on private land should be managed.

Cost Layers in Objective Function		**Constraint Layers**	
Attribute	**Use**	**Attribute**	**Use**
Area	Bigger patches better	Vegetation Communities	50% managed on private land
Shape	Simple shape better	Significant Species Habitats	50% managed on private land
Fragmentation	Least fragmented better	Climate Zones	50% managed on private land
Habitat Quality	Further from patch edge better	Long-Term Eroding Land	All vegetated LTE areas managed on private land
Opportunity Costs	Lower cost better	Salt Benefit Areas	All vegetated salt benefit areas managed on private land
Wind Erosion Potential	Higher erosion potential better	Vegetated Areas	Only vegetated areas can be managed
		Private Land	Only private land can be managed
		Protected Areas	Protected areas already managed

Four models are created to assess the trade-offs involved with including increasingly sophisticated systematic regional planning principles in the setting of geographic priorities for achieving vegetation management targets. Model 1 finds the set of cells for vegetation management that satisfies the broad regional target of managing 50% of native vegetation on private land at the minimum Opportunity Costs. Model 2 extends Model 1 to include the representativeness targets for biodiversity (50% of each Vegetation Community, Climate Zone and Significant Species Habitat) and minimises opportunity costs. Model 3 extends Model 2 to include the natural resource management targets of Salt Benefit Areas and Long-Term Eroding Land and minimises opportunity costs. Model 4 extends Model 3 and minimises not only Opportunity Costs but also the landscape ecology costs of patch Area and Shape, Fragmentation and Habitat Quality, and Wind Erosion Potential.

Key Findings

- Over 25% of remnant vegetation on private land is already managed. Meeting the NRM resource condition targets of managing 50% of remnant vegetation on private land will require a doubling of the existing managed area of remnant vegetation on private land - an increase of 99,751 ha.
- The distribution of current protected/managed areas of remnant vegetation is not representative of the range of biological and physical environments of the Corridor.
- The establishment costs of meeting the resource condition target for vegetation management range from $49 Million to $300 Million.
- The least expensive way of meeting regional resource condition targets for vegetation management has a total annual opportunity cost of $1,204,297 although the biodiversity and NRM benefits of this solution are poor.
- Including representativeness targets in vegetation management (i.e. ensuring at least 50% of each Vegetation Community, Climate Zone and Significant Species Habitat is managed) has an additional opportunity cost of only $84,000 per year (7%). The benefits for biodiversity of including these targets are likely to be substantially greater as will the effectiveness of vegetation management efforts in conserving biodiversity.
- Including the NRM targets in vegetation management (i.e. managing all remnant vegetation on Long-Term Eroding Land and Salinity Benefit Areas) has negligible extra biophysical or economic cost.
- Significant improvements in the Area, Shape, Fragmentation, Habitat Quality, and Wind Erosion Potential of managed areas of remnant vegetation can be achieved for minimal extra opportunity cost of only $40,000 per year (3% increase)

Policy Implications

- The establishment costs and opportunity costs of implementing resource condition targets in the Corridor are high compared to current government NRM funding. Sufficient funding to encourage vegetation management on the scale required to achieve regional resource condition targets is unlikely to become available in the foreseeable future. Hence, if vegetation management is to occur on a scale commensurate with resource condition targets there will need to be significant costs borne by private landholders. Market-based policy is required to have any chance of reaching regional NRM targets for vegetation management.
- Systematic regional planning can increase the biodiversity and NRM benefits of vegetation management actions at only marginal extra cost. Sites funded for vegetation management actions need to be spatially targeted for optimal NRM benefit and cost effectiveness.

- The shape of many areas selected in the spatial optimisation models is often complex and impractical for implementing vegetation management. Policy options need to be flexible and iterative to cope with the preferences of landholders for locating vegetation management actions on the ground whilst still working toward the most cost effective solution identified in the models.

Revegetation for Biodiversity

In addition to vegetation management, MCDA is used to identify geographic priorities for revegetation of local native species that satisfy NRM objectives at minimum cost. The regional resource condition target states that revegetation for biodiversity should increase the area of native vegetation by 1%. This target is not based on any ecological or conservation planning principles and systematic planning is required to identify priority sites for action to have maximum benefit for biodiversity. In this study we extend the 1% target and take a longer term view. This involves setting targets for revegetation so that 15% of each Pre-European Vegetation Community, Climate Zone and Soil Land System are represented by native vegetation either remnant or restored. A number of layers are used as costs and constraints in setting geographic priorities for revegetation for biodiversity:

Cost Layers in Objective Function		Constraint Layers	
Attribute	**Use**	**Attribute**	**Use**
Landscape Context	Cells closer to remnant vegetation better	Pre-European Vegetation Communities	15% of each community vegetated
Fragmentation	Fragmented best, then relictual, variegated, and lastly, intact	Climate Zones	15% of each Zone vegetated
Opportunity Costs	Lower cost better	Soil Land Systems	15% of each SLS vegetated
Wind Erosion Potential	Higher erosion potential better	Long-Term Eroding Land	All Long-Term Eroding Land vegetated
		Salt Benefit Areas	All Salt Benefit Areas vegetated

Five different models were created to identify priority sites for revegetation for biodiversity to assess the influence of incorporating increasingly sophisticated regional planning principles. Model 1 selects sites for revegetation that increase remnant vegetation by 1% at the minimum Opportunity Costs. Model 2 implements the more sophisticated representativeness targets for revegetation for biodiversity at minimum Opportunity Costs. Model 3 extends Model 2 by integrating the costs of Landscape Context, Fragmentation and Wind Erosion Potential. Model 4 also extends Model 2 to include the natural resource management targets of Salt Benefit Areas and Long-Term Eroding Land at the minimum Opportunity Costs. Model 5 combines Models 3 and 4 and includes both the NRM targets and the suite of cost attributes in the objective function.

Key Findings

- The minimum opportunity cost involved in increasing remnant native vegetation by 1% in the Corridor is $41,685 per year and requires an area of revegetation of 5,107 ha. The establishment costs of reaching the 1% revegetation target ranges between $2.5 and $15 Million. The most cost effective sites for revegetation would have minimal benefits for biodiversity and NRM and undertaking revegetation in these locations would not be a cost-effective use of NRM resources.

- Implementation of a 15% representativeness target in the Corridor (i.e. ensure at least 15% of each Pre-European Vegetation Community, Climate Zone and Soil Land System are represented by either remnant vegetation or revegetation) has a significantly higher opportunity cost of $706,000 per annum, requires 4 times the area of the 1% target (21,578 ha) and the establishment costs range between $13.8 and

$83 Million. However, the resulting geographic priorities for revegetation have a much better chance of conserving regional biodiversity.

- Further enhancement of the biodiversity and NRM benefits of revegetation by including Landscape Context, Fragmentation and Wind Erosion Potential costs) involves an increase in opportunity costs of nearly $150,000 per annum (a 21% increase).
- Including the NRM benefits of revegetating all Long-Term Eroding Land and Salinity Benefit Areas (not irrigated) requires an extra 6,000 ha of revegetation and around $215,000 per annum extra opportunity costs. The opportunity and establishment costs of revegetation to achieve wind erosion and salinity benefits are likely to be many times higher than the public benefits from reductions in these NRM benefits.
- The spatial distribution of areas for revegetation are a mix of new patches, infill of existing remnants, stepping stone patches and linking areas.

Policy Implications

- Current levels of funding for revegetation is unlikely to achieve the scale of revegetation required to achieve regional biodiversity targets. If the stated resource condition target of achieving a 1% increase in vegetation and the additional 15% representativeness target are to be met, significant costs must be borne by private landholders. Market-based policy mechanisms may greatly enhance the likelihood that these revegetation goals are met.
- Sites funded for revegetation actions need to be spatially targeted for optimal NRM benefit. The sites selected for short term funding should coincide with the high priority sites identified for meeting the long term 15% representativeness target.
- It is prudent to include Landscape Context, Fragmentation and Wind Erosion Potential in enhancing the location of revegetation for biodiversity, as the enhanced likelihood of success of revegetation in these priority locations and the increase in biodiversity benefits is likely to be cost effective.
- Including the NRM objectives of Salinity Benefit Areas and Long-Term Eroding Land in setting priorities for revegetation is very expensive and the costs far outweigh the benefits of revegetating these areas for biodiversity based on the parameters used in this study.

Revegetation for Biomass

The biomass model takes an economic rationalist point of view and selects the locations for biomass production that are the most profitable and have the lowest risk. The major constraint is that 100,000 green tonnes of biomass must be produced annually to supply the ITP plant. Returns can come from biomass production or from NRM credit payments. Constraints are also set so that biomass production does not cover more than 85% of each Pre-European Vegetation Community, Climate Zone and Soil Land System and hence preclude the achievement of biodiversity goals of representing 15% of each of these features.

Layers in Objective Function		Constraint Layers	
Attribute	**Use**	**Attribute**	**Use**
Returns from biomass	Higher returns better	Biomass production	Minimum of 100,000 tonnes
Salinity credits	Higher returns better	Pre-European Vegetation Communities	No more than 85% of each community under biomass
Wind Erosion Potential	Higher returns better	Climate Zones	No more than 85% of each zone under biomass
Risk of production	Lower risk better	Soil Land Systems	No more than 85% of each SLS under biomass

Four different models of biomass production are assessed. Model 1 is a straight profit maximising model which identifies the most profitable grid cells for biomass production that yield 100,000 tonnes per year. Model 2 maximises profit but also ensures that biomass production does not preclude the ability to represent 15% of each biophysical feature through revegetation. Model 3 extends Model 2 and includes consideration of the risk involved in biomass production and attempts to maximise the expected value of returns (returns x risk). Finally, Model 4 extends Model 3 and includes not only expected returns from biomass but also the returns from salinity and wind erosion credits.

Key Findings

- The network of sites that yield 100,000 tonnes of biomass at the highest NPV returns from biomass production include a total of 14,215 ha of land and return a NPV of just over $24 Million more than current land use (over a time frame of 100 years and discount rate of 7%). This estimate of profitability is however, likely to be conservative given the latest estimates of biomass species productivity in the Corridor (Hobbs and Bennell 2005). The spin-off salinity benefits total $584,576 in avoided costs to downstream users and wind erosion benefits total $364,046 in credits given the potential payment system developed in this study. The economic risk of these higher profit sites is fairly low.
- The most economic sites for biomass production occur mainly in spatially contiguous zones and tend to occur adjacent to irrigated areas and the flood plain. This is because these areas tend to be classified as minimal use land and hence are given a low opportunity cost. Biomass production in areas interspersing irrigated areas may have synergistic benefits whereby production is increased and raised water tables may be decreased.
- The most economic sites for biomass production for supplying 100,000 tonnes for a single Integrated Tree Processing plant do not preclude the implementation of biodiversity goals in the Corridor. However, the impact of biomass production on biodiversity may need further investigation if production is required to supply 2 or more ITP plants.
- Depending on landholder attitudes to risk, the returns to biomass production can be traded-off for increased certainty in production using the expected value of returns.
- The inclusion of market-based policy instruments like payments in the form of credits for public benefits of salinity and wind erosion mitigation will cost in the order of $1 Million in public funds and have only a minor impact on the total amount of public NRM benefits.

Policy Implications

- Experience from Western Australia suggests that the location of biomass production adjacent to cereal crops may reduce elevated water tables and provide the NRM benefit of mitigating dryland salinity. As a corollary, locating biomass production adjacent to irrigated areas in the Corridor may have similar salinity benefits in reducing land and river salinity.
- Thus, the NRM benefits of biomass production including salinity, wind erosion and potentially carbon, adds significant weight to investment in establishing a biomass industry in the Corridor. Biomass production seems to be a fairly attractive option with dual economic and environmental benefits.
- The establishment of biomass production not only represents an economic driver for private parties motivated by profit, but also yields significant public NRM benefits. However, the adoption of a credit scheme involving payments for NRM benefits such as salinity and wind erosion mitigation is expensive and does little to increase NRM benefits.

Policy Options and Design

A range of policy options exist to encourage large-scale vegetation management and revegetation (Connor and Bryan 2005). The most promising include invited tender grant systems, NRM credit systems, and biomass-based industry development. The policy options are required to provide incentives for large scale natural resource management actions that provide the multiple objective NRM benefits of salinity, biodiversity, wind erosion and carbon benefits (Connor and Bryan 2005). None of these policy options alone could feasibly facilitate the scale of revegetation and vegetation management required to meet multi-objective INRM resource condition targets in the Corridor. The best potential for achieving the targets is a multi-faceted policy mix involving the best elements from a variety of different policy options and tailored specifically to the different types of revegetation and vegetation management in the River Murray Corridor.

Invited Tender for NRM Contracts

- Invited tender for NRM contracts involves an auction design where tenders are specifically invited for vegetation management and revegetation contracts from landholders and community groups which propose action in high priority areas. This will facilitate the high degree of spatial targeting required to address high priority sites for NRM
- Tendering approaches may be applied to individual landholders, Local Action Planning (LAP) groups, or larger investors willing to negotiate on behalf of landholders
- Tenders should be invited from all landholders and groups with influence over high priority sites. However, prioritisation reduces market size and caution is required to avoid problems arising from thin markets
- Bids may be submitted that propose either the revegetation of local native species for biodiversity, or the management of remnant vegetation. There should be 2 classes of bids which are evaluated separately – revegetation and vegetation management.
- Differentiation in tender selection can be done based on the NRM benefits offered per dollar and the tenders offering the most cost effective actions selected for funding. Essentially, tenders offering revegetation and vegetation management over the largest area in high priority locations are a high priority for funding
- A reserve price may be set that specifies the maximum that will be paid per hectare of NRM action
- One advantage of this approach is that the maximum expenditure by the government will be known
- This approach is likely to increase the cost effectiveness of government money spent on revegetation, particularly for biodiversity. Our experience (Bryan *et al*. 2004a) suggests that around twice the environmental benefits can be gained from NRM funding using a tendering approach
- Tendering approaches have the advantage of requiring little institutional change. A tendering approach simply adds value to existing devolved grant schemes. In addition, the existing institutional infrastructure is already in place. All funded NRM actions should involve putting a management agreement or Heritage Agreement on sites proposed for NRM action
- Tendering approaches for individual landholders and groups are particularly suited to the less economic local native species plantings required for biodiversity goals. Whilst tendering approaches could also be applied to encourage other types of NRM actions such as revegetation such as fodder crops and woodlots, the NRM benefits of these

types of revegetation are limited and funding spent on these efforts may be better spent of high priority actions with multiple NRM benefits in high priority sites.

- Established techniques and appropriate data for tender ranking and selection are available (Bryan *et al*. 2004a)
- Significant investment is required to get the auction scheme off the ground as the responsibility for the design of revegetation projects is devolved to the landholders and substantial information is required upfront to support their bid
- A key to the success of tendering schemes in NRM is the supply of adequate information to landholders to support their bid
- Capital, time preference and information constraints would likely be more significant for a tendering policy focussed on individual smaller enterprises rather than larger institutional investors
- Capital and information constraints may be overcome by offering contracts with evenly spread annual payments. This may also increase certainty on behalf of the funding agency as payments are made contingent upon performance.
- The tendering system needs to be ongoing. Priorities for NRM action can be recalculated and updated each round. This iterative approach enables consideration of the NRM impacts expected from the projects funded in the previous round and an assessment of how these change future geographic priorities. This iterative approach can also integrate new information affecting geographic priorities as this becomes available. Tools can be developed to support this (Bryan *et al*. 2004b).

NRM Credits

- An NRM credit system (Ward and Connor 2004, Willis and Johnson 2004) could be integrated with the tendering system suggested above. Credit systems can be set up as a straight payment to landholders for actions that achieve NRM benefits initially, with a cap and trade system potentially implemented at a later date.
- Salinity credits could include payments for revegetation that reduces the cost of future salt loads to the River Murray. A well developed technical capacity is established to assess salinity impacts of revegetation and dollar benefits to downstream users. However, there is some risk due to the uncertainty surrounding the effectiveness of revegetation in reducing salt loading over time. To alleviate this, risk management could involve setting an upper bound on payments for revegetation at some fraction of the estimated cost of salinity to downstream users (e.g. 50%).
- A salinity credit scheme may be extended to a broader-focussed NRM (or Ecosystem Services) credit system where landholders receive payments for improving biodiversity or reducing wind erosion. However, there is significantly more risk attached to the extended credit system as measurement of the value of benefits to wind erosion and biodiversity is more difficult.
- A credit system involving government payments to landholders and groups for addressing the multiple objective resource condition targets of salinity, wind erosion and biodiversity may encourage some NRM actions. However, given the level of government funding likely to be available in the foreseeable future and typical levels of costs borne by landholders, an NRM credit system consisting of payments for salinity, wind erosion and biodiversity benefits is unlikely to encourage the scale of actions required to achieve resource condition targets. Additional economic drivers are required to facilitate NRM action on this scale.
- The potential of carbon trading as an economic driver for achieving large scale NRM actions in the Corridor is considerable. Thus, whilst a detailed assessment of the economic potential of carbon sequestration in the Corridor is required, initial

calculations based on the latest production estimates and price figures suggest that landholders may make an income from carbon trading comparable with existing agriculture. Carbon credits may also be integrated with salinity, biodiversity and wind erosion credits. NRM actions such as vegetation management and revegetation of local native species can have multiple objective salinity, biodiversity, wind erosion and carbon benefits. A policy mix involving salinity, biodiversity, wind erosion and carbon credits may provide a combined income from these sources large enough to provide sufficient incentive to encourage the scale of NRM actions required to meet resource condition targets.

- The fact that the Commonwealth has not ratified the Kyoto protocol has not dissuaded other states from initiating programs focussing on carbon trading. Victoria's CarbonTender program combines a tendering system for revegetation for biodiversity like the one outlined above with the future option of selling carbon credits earned from revegetation efforts on the global market.
- Before a multiple NRM benefit credit system could be implemented, research would be required to fully develop standard and accounting frameworks for quantifying appropriate credit payment levels for biodiversity and wind erosion mitigation and carbon sequestration actions. This should build on existing work quantifying the value of biodiversity (Hatton MacDonald and Morrison 2005), wind erosion (Williams and Young 1999) and the extensive literature and standards for carbon sequestration and trading.

Biomass Industry Development

- A biomass industry in the corridor is likely to be profitable as a private enterprise and can result in considerable NRM benefits at minimal government expense. An industry development policy may hasten the uptake of the opportunity.
- This policy option involves putting out to tender a single biomass industry contract which involves managing the complete operations of a biomass industry plant in the Corridor as a commercial enterprise including the local production, processing and marketing of biomass products. Industry development may also involve market research and local extension work. It is not envisaged that biomass industry development will be expensive.
- Tendering approaches involving larger investors may be best aimed at utility-type companies looking to run a biomass processing plant and contract local landholders to revegetate for biomass industries. However, a farmer co-operative type model may also be a possibility.
- This kind of model is widely used in forestry contracts and a similar model is used in the context of biomass production in Western Australia.
- A private enterprise model achieves economies of scale as all of the processes from production to market are managed by a private company
- Much of the risk involved in the biomass industry is borne by the company rather than the public
- For a biomass industry model to be successful, cash flow timing constraints that make perennial plantings unattractive to landholders would have to be addressed. Contracts guaranteeing fixed annual payments may be required to encourage adoption of perennial woody species. This would be the responsibility of the company.
- Extra payments for NRM benefits such as salinity and wind erosion credits may not result in cost-effective additional NRM benefits. However, the market may support 2 or more ITP plants which will increase the NRM benefits of a biomass industry.

Market research should include a quantitative investigation into the size of the market for biomass products in the Corridor.

A Policy Mix for NRM

As mentioned above, no single policy is likely to encourage the scale of NRM actions required to meet resource condition targets in the Corridor. The three options discussed above used together, may have the potential to achieve multiple objective NRM targets. The biomass industry development option has potential to encourage large scale revegetation of biomass species. This is a low cost option for government as biomass seems to be an economically viable exercise in the Corridor. Biomass plantings motivated solely by profit can also provide considerable salinity and wind erosion benefits. However, biomass production does not offer significant biodiversity benefits. The tendering system for NRM contracts has the potential to encourage some NRM actions, especially those contributing biodiversity benefits such as vegetation management and revegetation of local native species. The NRM credit payment system though, which includes payments for salinity, biodiversity, wind erosion and carbon credits, has the greatest potential to encourage cost effective, large scale, multiple objective NRM actions especially for biodiversity. Overcoming the barriers to carbon trading is the key precursor to the success of this policy option.

Conclusion

Systematic regional planning was developed in this study to assess the feasibility of different policy options for encouraging the large scale NRM actions, including vegetation management and revegetation, required for achieving stated regional resource condition targets for NRM. Geographic priorities are identified for the NRM actions of vegetation management and revegetation based on biophysical and economic principles for input into a spatial multi-criteria decision analysis framework. Spatial optimisation techniques are used within the MCDA to identify priority sites for NRM actions that simultaneously and cost-effectively achieve the multiple NRM objectives of salinity, biodiversity, wind erosion and carbon. In this study we present a full implementation of systematic regional planning for multiple objective NRM in the South Australian River Murray Corridor.

Systematic regional planning revealed that given the current levels of government funding, regional resource condition targets are unlikely to be met by either vegetation management or revegetation without private landholders bearing a significant portion of the cost. It was also found that by implementing systematic and intelligent planning, salinity and wind erosion benefits could be achieved by vegetation management in addition to the biodiversity goals at minimal extra cost.

In planning for revegetation, we considered that the resource condition target of a 1% increase in vegetation was not likely to greatly enhance regional biodiversity, especially if the least expensive options were taken. Instead, we design and implement SRP based on a 15% representativeness target as a long term goal for revegetation. The amount of revegetation required to meet this target is about 4 times more expensive than the 1% target but the NRM benefits are likely to be substantially more. Including consideration of Landscape Context, Fragmentation status and Wind Erosion Potential in the model increased the likely NRM benefits from revegetation at some extra cost. Including the NRM benefits of revegetating all Salinity Benefit Areas (as modelled by SIMPACT over a 100 year time frame) and Long-Term Eroding Land was not cost effective.

Biomass production was found to be potentially viable in the Corridor and the most profitable sites could return a net present value of $24 Million more than existing land uses. Biomass production could also provide significant NRM benefits for salinity and wind erosion at very little cost to government. The integration of a NRM credit system to encourage biomass plantings in high priority areas for salinity and wind erosion benefits is not likely to be cost effective.

Market-based policy mechanisms are suggested for encouraging vegetation management and revegetation of local native species to achieve multiple objective NRM benefits. An invited tendering system is suggested which provides a spatially targeted approach for encouraging NRM actions. Multiple benefit NRM credit systems could also be implemented and possibly combined with the tendering system. Carbon credits especially have considerable potential for encouraging the large scale NRM actions required to meet the multiple objectives of salinity, biodiversity, wind erosion and additionally, carbon sequestration, in the Corridor. A biomass industry development program is also proposed which may involve market research and tendering of a biomass production contract to utility and similar companies with experience in biomass industries.

In this study we have identified future options for most cost effectively addressing NRM targets in the South Australian River Murray Corridor. We have quantified the cost, feasibility and impacts of achieving a few selected resource condition targets and discussed policy instruments which may provide the greatest chance of meeting targets. Future directions for research include extending the concept of SRP, integrating climate change impacts, and designing policy that optimally encourages NRM actions in the priority locations identified by SRP.

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1. Introduction

In many human-dominated regions, development of natural resources has resulted in environmental degradation. Development has occurred primarily for agriculture which usually involves both the broadacre clearance of deep-rooted native vegetation and replacement with shallow-rooted annual crops and pastures, and the grazing of remnant vegetation by livestock. The effects of this large scale land clearance commonly results in the degradation of biological, land, and water resources. Biological resources are degraded through the direct removal of native habitat. Soil resources are degraded through the increased susceptibility to erosion, compaction, and changes in physical and chemical properties. Water resources are degraded through increased recharge of groundwater, rising water tables and salinisation of surface waterways. Degradation of natural resources occurs over geographically and biophysically diverse parts of the landscape and natural resource management (NRM) actions are required over a broad spatial scale to address these degrading processes. In this study, we focus on the South Australian River Murray Corridor (or simply *the Corridor*) where clearance of native vegetation for agricultural development in the Corridor has lead to environmental problems such as biodiversity degradation, wind erosion and increased salinity in the River Murray.

In natural resource management complex decisions are required to prioritise the type, timing and location of actions that most cost effectively redress multiple degrading processes. The concept of *integrated natural resource management* (INRM) provides a framework for the integrated management of natural resources like land degradation, biodiversity, water quality, and climate change. Furthermore, INRM involves the integration of economic and social aspects of natural resource management. These range from agricultural land use and regional economic and social impacts of land use change to the integration of private landholders, community groups, government and non-government organisations in the planning administration and implementation of natural resource management. This study embraces the entire concept of INRM.

Planning for natural resource management in Australia and elsewhere has become increasingly regional in focus and administration. This has been evident in Australia with the regional implementation of major natural resource management schemes such as the Natural Heritage Trust (NHT) and National Action Plan for Salinity and Water Quality (NAP). Regional planning for natural resource management in South Australia is now the responsibility of regionally-based Integrated Natural Resource Management Groups. South Australia has been divided into eight INRM regions and INRM Groups have been charged within planning and administering funds for natural resource management.

Many regional agencies have developed, or are in the process of developing, NRM plans and associated investment strategies to identify the major environmental assets and threatening processes, and the NRM actions required to address them. The centerpiece of regional NRM plans and investment strategies is usually a set of *resource condition targets*. However, these plans rarely provide sufficient information, especially spatial detail, to prioritise specific on-ground investment of limited funds for natural resource management actions to achieve these targets. Assessment of the costs and impacts of achieving NRM targets is rare as is any planning for the most cost effective ways to achieve NRM targets. Systematic planning based on biophysical and economic principles is required to guide regional investment in NRM by identifying geographic priorities for NRM actions that maximise the benefits of these actions and enable regional NRM targets to be achieved cost effectively.

The scale of NRM actions required to achieve regional resource condition targets can be large as is the case in the Corridor. NRM actions are expensive and are required on largely privately-owned land. Landholders are currently unwilling to undertake substantial investments in NRM actions as establishment is costly and there is a long term loss of revenue from current land use. The on-farm economic benefits of NRM actions are generally regarded as insufficient to compensate for their costs. In the case of NRM actions the costs are usually incurred by the private landholder whilst most of the benefits are realised over long time periods and accrue predominately off-farm to the wider community who do not share in the initial investment costs. In addition there is usually some uncertainty surrounding the benefits received.

The aim of this study is to assess the feasibility of achieving the scale of NRM actions, including vegetation management and revegetation, required to meet stated regional resource condition targets for NRM. We address the multi-objective natural resource management issues of salinity, biodiversity, wind erosion and carbon, provide support for complex NRM decision making, and assess policy options for providing incentives to encourage NRM actions.

To achieve this, we develop the concept of *systematic regional planning* (SRP) for multiple objective natural resource management. Systematic regional planning is conducted within a spatial multi-criteria decision analysis (MCDA) framework and enables the identification of geographic priorities for NRM actions that most cost effectively address multiple natural resource management objectives. Trade-offs between NRM benefits and the cost of NRM actions are quantified and this information is used to support decision making. The cost of the large scale NRM actions required to meet regional resource condition targets is quantified and policy options are assessed for their ability to encourage large scale NRM actions.

The Corridor study area falls within the South Australian Murray-Darling Basin (SA MDB) INRM Region. Strategic INRM planning has primarily focused on the development of the Catchment Plan (RMCWMB 2003) and subsequently the INRM plan (INRM Group 2003a) and its associated investment strategies (INRM Group 2003b&c). On-ground NRM actions are largely carried out by Local Action Planning (LAP) groups (AACM International 1997, Murray Mallee Local Action Planning Association Inc 2001) and private individuals. The NRM plans are supported by the biodiversity plan for the SA MDB (Kahrimanis *et al*. 2001) and Land and Water Management Plans. In the INRM Plan and Investment Strategies (INRM Group 2003b&c) the SA MDB INRM Group has committed to specific resource condition targets (Appendix 1) for large scale vegetation management and revegetation of perennial species to ameliorate biodiversity degradation, and decrease river salinity and wind erosion.

SA MDB INRM resource condition targets (INRM Group 2003c) are multi-objective and those specific to this project include river salinity, biodiversity, and wind erosion. The SA MDB INRM Plan does not specifically address carbon sequestration for abatement of the enhanced greenhouse effect and associated climate change. However, we consider carbon to be an important objective in natural resource management and there is increasing government interest in the potential implications of the Kyoto Protocol if Australia ratifies it. In addition, carbon trading has considerable potential as an economic driver for revegetation. Hence, we include discussion of carbon as an objective for NRM in the Corridor.

The NRM actions of vegetation management and revegetation have many diverse benefits (Ive and Abel 2001). However, for the purposes of this study, vegetation management, which includes all of the activities necessary to manage remnant vegetation for biodiversity conservation values, is considered to have benefits only for biodiversity. In reality, there may also be some salinity and wind erosion benefits if badly degraded vegetation is rehabilitated through management but these effects are not considered in this study. Vegetation management can be expensive and the market-based opportunities for encouraging large scale vegetation management are limited. Revegetation can also have substantial costs (Ive and Abel 2001). However, market-based mechanisms exist that may encourage the scale of revegetation required to reach regional resource condition targets in the Corridor. Thus, we consider three different types of revegetation in this study (although fodder crops are not analysed in detail):

1. Revegetation of eucalypts for biomass industries
2. Revegetation of fodder crops for stock feed
3. Revegetation of local native species

In this study, different revegetation types are considered to have distinct NRM benefits. All revegetation types are considered to have the same salinity impact as they are all thought to reduce groundwater recharge to zero upon establishment by eliminating recharge and thereby reducing river salt load contribution from dryland areas. They are also all considered to eliminate the impact of wind erosion upon establishment through the soil binding effect of the roots. However, revegetation of local native species is the only type that is considered to provide biodiversity benefits. Biomass monocultures may offer some biodiversity benefits such as food sources for high motility species and habitat for soil biota (Salt *et al*. 2004) but these effects are not considered in this study. Revegetation of local native species and biomass may also have carbon sequestration benefits.

As discussed above, processes of environmental degradation operate heterogeneously across the landscape and NRM actions at different sites in the Corridor offer different levels of NRM benefit. For maximum NRM benefit, actions need to be targeted in high priority geographic locations. The benefit of vegetation management and revegetation for biodiversity depends of the spatial arrangement of the NRM actions. A range of principles exist for identifying geographic priorities for vegetation management and revegetation derived from conservation biology and landscape ecology (Margules and Pressey 2000). The benefit of revegetation for salinity and wind erosion also depends on the spatial location of the plantings. Salinity benefits are dependant upon the geohydrologic and groundwater characteristics of the site of the plantings. The benefit of revegetation in wind erosion mitigation depends upon the location of revegetation and the susceptibility of soil to erosion. Economic processes also vary spatially. The profitability of biomass production varies spatially with productivity, opportunity and transport costs.

Systematic regional planning is implemented within a spatial multi-criteria decision analysis framework which provides a structured approach to analysing complex decisions like those required in planning for multi-objective NRM (Prato 1999). The spatial MCDA framework involves a number of stages. The first stage is the definition of the decision problem. The multiple decision criteria or *attributes* are then constructed. This requires the quantification of the spatial distribution of the underlying biophysical and economic processes that influence NRM decisions. These attributes take the form of a number of GIS layers and can be used as cost layers or as targets. The decisions involved in spatial MCDA for systematic regional planning involve selecting geographic locations to undertake specific NRM actions. The decision rules are the analytical engine of the MCDA. The decision rules used in SRP are spatial optimisation techniques based on integer programming. Integer programming enables the quantitative formulation of the multi-objective NRM decision problem. The MCDA framework then involves sensitivity analysis and finally making recommendations for the strategic implementation of specific NRM actions in specific geographic locations.

The objectives of this study are listed below and these also provide a road map outlining the structure of the report:

- Provide the necessary background and concept development of strategic regional planning for multiple objective natural resource management;
- Review NRM targets and actions relevant to the SA River Murray Corridor;
- Implement strategic regional planning for multiple objective NRM in the River Murray Corridor using a spatial MCDA framework. This involves:
    - Definition of the problem

  - o Assembly of evaluation criteria data which includes using a variety of spatial modelling techniques based on established biophysical and planning principles to create GIS layers of:
    - Salinity benefits
    - Biodiversity priorities for both vegetation management and revegetation including costing these actions
    - Opportunity costs of agriculture
    - Economic returns from biomass production including a sensitivity analysis
    - Wind erosion
  - o Define the decision alternatives
  - o Define and implement the decision rules using spatial optimisation to identify geographic priorities for the NRM actions of vegetation management, revegetation of local native species, and revegetation of biomass such that resource condition targets are met cost effectively
  - o Provide flexibility in outputs, assess the spatial distribution of priority NRM actions, and assess and discuss the feasibility of meeting resource condition targets
- Discuss the policy options available for encouraging large scale NRM actions in the Corridor. Recommend the best alternative option(s) in the context of the economic, environmental, social, and institutional outcomes. Discuss barriers and how to overcome them, and compare alternative option(s).

It should be noted here that the solutions provided by the systematic regional planning models presented in this study are not intended for rigorous implementation. The funds available to buy the necessary land, or to cover the considerable opportunity or establishment costs to landholders involved in undertaking NRM actions for public environmental benefits are unlikely to become available. The models are designed for two purposes. Firstly, they provide estimates of the costs involved and the trade-offs that need to be made in implementing the most cost effective means of achieving regional natural resource management targets. Secondly, they identify geographic priorities for on-ground actions for achieving regional NRM targets as a basis for smart use of policy instruments to best encourage NRM actions in these priority locations. The mapped priorities are indicative of priority areas rather than absolutes. They are not intended as a top-down directive, but rather guide for assessing bottom up willingness of private land holders to improve NRM outcomes.

2. Decisions and Multiple Objective NRM

Modern environmental issues are characterised by a number of physical, biotic, social and economic factors that complexly interact over geographic space. Management of these issues requires an interdisciplinary focus and the ability to systematically integrate many diverse processes and perspectives. In the context of the natural resource management issues characteristic of agricultural regions, a number of factors are involved and complexly interact including biodiversity, surface and groundwater quality and quantity, soil erosion, dryland and irrigated agricultural production, and community. Management involves making decisions within this world of complex, conflicting parameters.

Making complex decisions that involve a trade-off between multiple criteria is a natural process. Decision theory has long been used in agriculture, economics and engineering to help structure and support complex decisions (Anderson *et al*. 1977). Spatial multi-criteria decision analysis is a decision theory technique for evaluating trade-offs involved in making complex decisions in geographical space. In this study we use decision theory to structure the problem of achieving natural resource management goals most cost effectively and MCDA to identify the geographic priorities for NRM actions.

Research into the assessment and management of complex environmental issues is increasing. However, probably because of its inherent interdisciplinarity, research has lacked a common framework and terminology, and a coherent set of methods for addressing these hard problems. In this study we propose a decision theory framework for structuring and analysing NRM decisions. This section begins by explaining the decision theory and spatial multi-criteria decision analysis methodologies. This is followed by an overview of how the methodologies are applied to systematic regional planning for multiple objective NRM.

2.1. Decision Theory

Decision theory provides a framework which can be used to support decisions which meet explicitly stated objectives as to the desired state of nature resulting from the decision. Decision theory caters for decisions made under certainty, uncertainty and risk. In decisions made under certainty the decision-maker has perfect information on the states of nature and has only to analyse this information in order to make the optimal decision. In decisions made under uncertainty, the decision-maker has no knowledge about the states of nature resultant from the decision. In decisions made under risk, the decision-maker has knowledge of the probabilities of different states of nature and this can be used to inform the decision. Decision theory also allows for different decision strategies such as optimism and pessimism. Under an optimistic strategy, the decision-maker strives to either choose the option that maximise the maximum benefit or minimises the minimum cost. In a pessimistic strategy, the decision-maker aims to make the decision that maximises the minimum benefit or minimises the maximum cost (Anderson *et al*. 1977, Webster 1995).

Decision theory also provides a formal protocol for structuring decision analysis problems from the statement of objectives to making the decision (Possingham 2001, Possingham *et al*. 2001). Four steps have been distinguished in the rational decision making model (McKenna 1980):

1. Problem definition
2. Search for alternatives and selection criteria
3. Evaluation of alternatives
4. Selection of alternatives

2.2. Spatial Multi-Criteria Decision Analysis

Multi-criteria decision analysis (MCDA) is a powerful tool for supporting complex decisions constrained by multiple competing objectives and criteria. Spatial MCDA is a subset of MCDA techniques in which location plays a role in the decision variables. The spatial dimension adds a new level of complexity to natural resource management decisions. Spatial MCDA is ideally suited to the analysis of the kind of complex decisions required within a spatial context as are common in natural resource management (Hajkowicz *et al*. 2000). There are two main types of spatial MCDA – spatial Multi-Attribute Decision Making (MADM) and spatial Multi-Objective Decision Making (MODM) (Malczewski 1999).

MADM involves a set of alternatives and a set of attributes. The alternatives are decision variables which, in this study, are grid cells in a raster GIS which are used to represent the landscape. Let the number of grid cells equal *m*. Examples of the kind of decision that can be made in this study include whether to revegetate a grid cell for biodiversity or not, or whether to manage the vegetation of a grid cell or not. Attributes describe the state of nature for each decision variable. Within a GIS, attributes are stored as layers that capture the spatial variation in attribute values. Examples of the type of attributes relevant to this study include the biodiversity priority of each patch for vegetation management or the river salinity benefit achieved by revegetating each grid cell. Let the number of attributes equal *n*. We can designate attribute values as x_{ij} , which represents the value of the j^{th} attribute for each alternative *i* such that *i* = 1, 2,…, *m* and *j* = 1, 2, …, *n*.

We can then construct a decision matrix for the MADM problem described above which describes the alternative-attribute relationships. The rows of the decision matrix represent each decision variable (or grid cell) and the columns represent the attributes. The cells of the matrix contain the measured data values for each alternative *i* of each attribute *j* (Table 1).

	Attribute 1	**Attribute 2**	**…**	**Attribute *n***
Alternative 1	x_{11}	x_{12}	…	x_{1n}
Alternative 2	x_{21}	x_{22}	…	x_{2n}
…	…	…	…	
Alternative *m*	x_{m1}	x_{m2}	…	x_{mn}

Table 1 – Decision matrix for a MADM problem. x_{ij} , score for the ith alternative (*i* = 1, 2,…,*m*) with respect to the j^{th} attribute (*j* = 1, 2,…,*n*) (Source Malczewski 1999).

MADM analyses are essentially selection procedures because each attribute is considered an objective. Alternatives are selected providing they satisfy some objective condition for each attribute. These kinds of analysis are common in GIS- and database-type queries. However, in MODM analyses, the objectives are distinct from but functionally related to the attributes. In MCDA terms, the objectives can take two forms – that of an objective function and constraints. Objectives are a set of functional relationships between the decision variables and the attributes. The objective function in MODM analyses usually tries to minimise or maximise some function of the attributes. Constraints are a set of conditions (also functions of the decision variables and the attributes) that limit the set of feasible alternatives and ensure that the system meets some explicit state of nature. In this study, the MODM technique is used to identify sites for natural resource management actions that meet resource condition targets at minimum cost.

Malczewski (1999) identifies seven aspects of spatial MCDA which operationalise the stages of decision theory listed above specific to spatial MCDA:

- **Problem Definition** - In spatial MCDA, problem definition involves thinking through the structure of the decision problem, assembling, visualising and manipulating data (usually in a GIS) and gaining a thorough understanding of the complexity of the system of interest.

- **Evaluation Criteria** – Evaluation criteria are the objectives and attributes of the decision problem. This includes specification of a comprehensive set of objectives (including the objective function and constraints) that characterise all aspects of the problem and the attributes that provide a measure or indicator for achieving the objectives. Attributes with different scales may need to be rescaled so that they can be numerically compared in a coherent and commensurate way.
- **Alternatives** – Alternative are the decision variables. In spatial MCDA they are the spatial units, usually grid cells or polygons. Each spatial unit is a decision variable which may be considered to take on a particular state (e.g. change land use type) or value of some entity (e.g. increase the amount of production). Constraints may also be used to mask out areas where decisions are inappropriate or not relevant (e.g. urban areas or water bodies).
- **Criterion Weights** – Weights are commonly used to reflect the priorities of the decision maker with respect to the relative importance of the attributes. Weights are used to help combine attributes measured in different units and incorporate the bias of the decision maker in an explicit way.
- **Decision Rules** – Decision rules or *aggregation rules* are the means by which alternatives are evaluated. The form of decision rules is dependent upon the nature of the decision variables, objectives and attributes. In MODM this usually takes the form of an optimisation procedure such as mathematical programming, genetic algorithms or simulated annealing. The decision rules attempt to find a set of alternatives that meet the objective function and satisfy the constraints of the decision problem.
- **Sensitivity Analysis** - Undertaken to assess the robustness of the decision outcome to changes in all parts of the decision problem.
- **Recommendation** - Involves making prescriptions for future action based on the decision outcomes.

Spatial MCDA is often conducted within a GIS environment (Carver 1991, Chakhar and Martel 2003). Apart from a notable exception (Idrisi), few GIS packages have the functionality to inherently support complex multiple objective decision making. Decision theory tools such as MADM and MODM have been developed and integrated with GIS (Jankowski 1994, Chakhar and Martel 2003) often on an *ad-hoc* basis. In this study, we use GIS to manage the underlying spatial data, to create new data layers based on spatial process models, and to present the results of decision analyses. The MCDA occurs externally to the GIS.

2.3. Integrated Natural Resource Assessment, Modelling and Planning

There is an increasing realisation that biological, physical, economic and social processes are inextricably linked and quantitative analyses for supporting multiple objective NRM decisions have to consider and account for this complexity. As a result, an increasing number of studies are moving away from single issue simplification and analysis for informing NRM decisions and tackling complex multiple objective NRM assessment, modelling and decision analysis. This is an essential evolutionary step for quantitative NRM studies if these studies are to provide realistic and implementable policy recommendations.

However, coherent theoretical foundations for the quantitative, systematic, multiple objective assessment, modelling and planning for supporting complex spatial NRM decisions have not been well developed. Recently emerging is a new, integrated hard problem science which deals with complex problems that are impossible to deal with within the confines of any single discipline (Costanza and Jorgensen 2002). The fundamental tenets of hard problem science include concepts such as synthesis, analysis and modelling, integration, pragmatism, complexity, scale (Costanza and Jorgensen 2002). Harris (2002) and Parker *et al*. (2002) describe the elements of integrated assessment and modelling which is a central theme of hard problem science. Integrated assessment and modelling includes quantitative and integrated consideration of biological, physical, economic and social aspects, especially with regard to natural resource management. This study fits neatly within the hard problem science genre.

Practical applications of truly integrated assessment and modelling for tackling the hard problems of NRM are methodologically disparate. Examples of these analyses have come from diverse disciplinary backgrounds each with their own distinct techniques and focus. Most studies in integrated assessment and modelling for NRM focus on making recommendations for land use change. Studies tend to fall into two groups. There are those studies whose aim is to be truly integrative and address multiple objectives and there are studies that tend to focus on limited objectives but use sophisticated planning tools to identify priorities for land use change.

Many studies have aimed to address single primary objectives such as water quality and sedimentation (Khanna *et al*. 2003, Lu *et al*. 2004), nutrients (Seppelt and Voinov 2002, 2004), salinisation (Greiner and Cacho 2001), forest production (Turner *et al*. 2002), wetland restoration (Newbold 2002) and many examples in reserve selection and biodiversity (see Section 5.1.2). These studies often include economic and agricultural analysis in land use planning and often focus on developing advanced spatial planning and decision support techniques such as MCDA and spatial optimisation techniques.

There have been several studies whose aim is the integration of multiple objectives in land use planning and natural resource management. One of the largest such studies in Australia is the ongoing Heartlands project (Cresswell *et al*. 2004) which aims to develop integrated land use planning given the multiple objectives of dryland salinity, biodiversity, water yield, and agricultural production within a spatial context. Hajkowicz *et al*. (2003) made some progress towards integrated modelling, assessment and planning for NRM in the Strategic Landscape Investment Model which identifies investment priorities for NRM actions in the landscape. Williams *et al*. (2004) demonstrated an approach to targeting revegetation for salinity and water quality benefits. Hill *et al*. (2005) present a multiple objective approach (ASSESS) to the assessment of the environmental condition of Australian environments. Santelmann *et al*. (2004) assess alternative futures for agriculture in Iowa integrating production, water quality and biodiversity objectives. However, these more integrative and multiple objective type studies could benefit from the more sophisticated planning and structured decision analysis techniques more often found in studies addressing fewer objectives.

Studies that aim to be truly integrative and address multiple objectives using sophisticated planning tools seem to be rare although progress is being made. Systems modelling combined with optimisation is being increasing used to develop integrated, multiple objective, systematic planning tools (Costanza *et al*. 2002, Seppelt and Voinov 2002, Greiner 1999, 2004). Wang *et al*. (2004) have made a significant advance in combining multiple production and NRM objectives and sophisticated spatial planning techniques. In this study, we bring together principles and techniques from a wide range of fields including economics, geographic information science, decision theory, operations research, conservation biology/landscape ecology and geohydrology.of the Corridor. We attempt to further the application of integrated modelling, assessment and spatial planning for multiple objective NRM.

3. Description of the Study Area

The outer boundary of the River Murray Corridor study area in South Australia has been defined as a 15 km buffer from the 1956 floodplain stretching from the Victorian/NSW border in the east to Tailem Bend in the south (Figure 1). The Corridor covers an area of 1,217,000 hectares or 12,170 square kilometres. This includes some 108,000 ha of floodplain (defined as the area submerged by the 1956 flood, Figure 2), approximately 628,000 ha of cleared dryland area (Figure 3) and 511,000 ha of remnant native vegetation. In addition, there is approximately 50,000 ha of irrigated agriculture (Figure 4). An area of 193,000 ha is protected for conservation purposes including National Parks and Wildlife Reserves, voluntary Heritage Agreement Areas and the Bookmark Biosphere Reserve. Approximately 956,000 ha is unreserved land privately owned as freehold or managed within crown lease tenure.

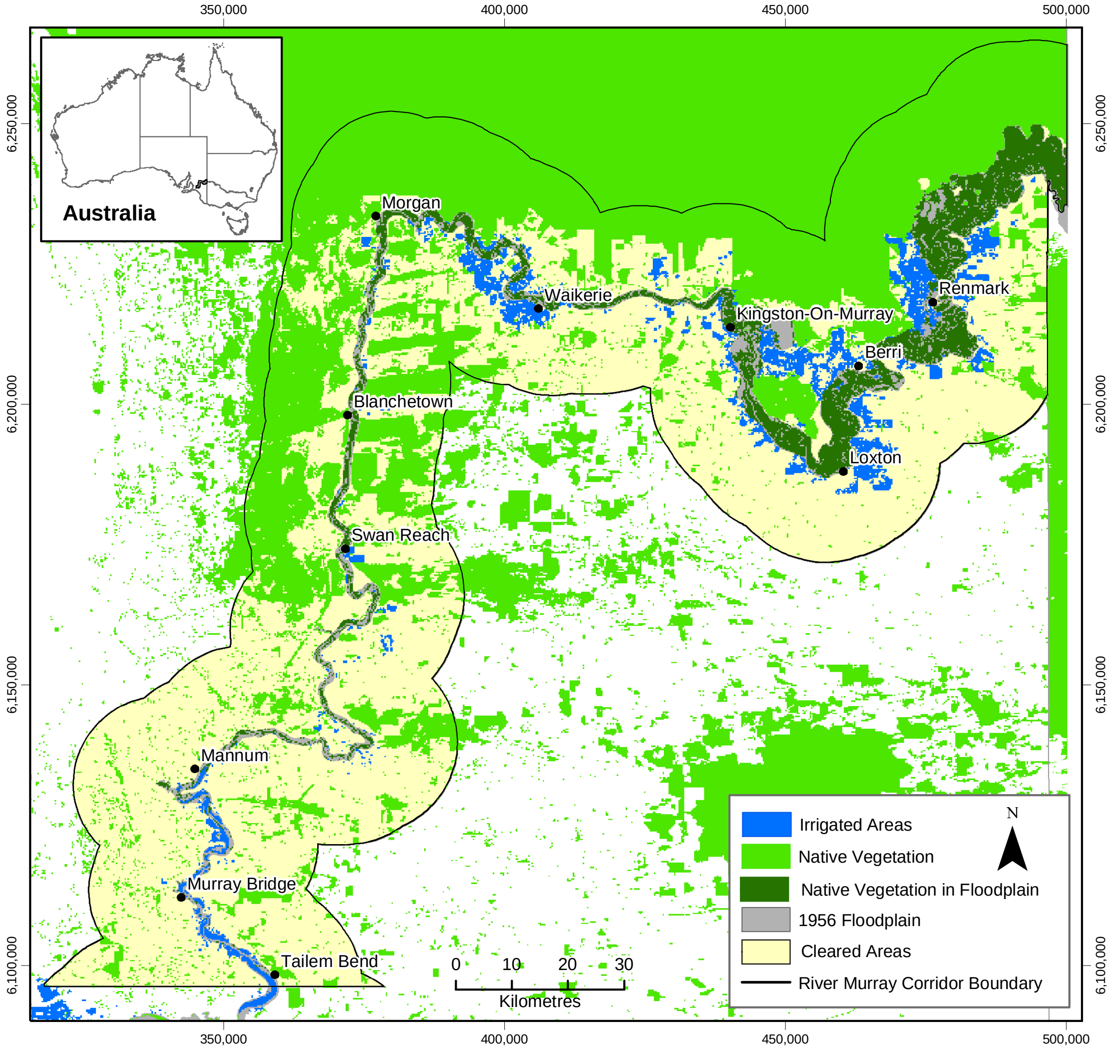

Figure 1 – Location map of the South Australian River Murray Corridor.

Figure 2 –River Murray including lower lying floodplain areas (left and foreground) and dryland Corridor areas above the cliffs to the right (Photo T.E. Schultz 2004).

Figure 3 – Dryland agricultural landscape near Blanchetown (Photo T.E. Schultz 2004).

Figure 4 – Irrigated horticulture including grapes in the foreground west of Kingston-on-Murray (Photo T.E. Schultz 2004).

The Corridor covers a diverse range of landscapes from the moist, cool, hilly eastern edge of the Mt. Lofty Ranges in the south-west of the study area to the warm dry plains of the Mallee in the north-east of the Corridor. Mean annual rainfall varies from 226 mm/yr in the north-east to 662 mm/yr. Mean annual temperature ranges from 13.2 ^{o}C in the south-west to 16.8 ^{o}C in the north-east. The South Australian Department for Environment and Heritage (DEH) has identified and mapped remnant native vegetation communities in the Corridor. About 42% of the Corridor remains in a semi-natural state under remnant vegetation. This is high compared to other agricultural regions in South Australia. However, much of this remnant vegetation is degraded to varying degrees, predominantly by livestock grazing. Remnant vegetation communities in the dryland areas include native grassland and shrubland, mallee woodland and open woodland in the eastern Mt. Lofty Ranges. Many remnants provide existing and potential habitat for rare and threatened species (Kahrimanis *et al.* 2001). The floodplain also includes ecologically significant wetland ecosystems.

Soils in the Corridor are commonly sandy and nutrient poor. However, parts of the Corridor near the river are characterised by rich alluvial soils suitable for intensive irrigated agriculture. Regional groundwater systems are naturally saline and flow towards the River Murray, delivering a natural influx of salt to the river. Land clearance has exacerbated this process through increased groundwater recharge (Cook *et al*. 2004).

Land use in the Corridor is a mosaic of irrigated and dryland agriculture. Irrigated agriculture occurs close to the River Murray and is dominated by dairy, fruit and grapes. Irrigated agriculture in this region, especially fruit and grapes, is some of the highest value irrigated agricultural production in the Murray-Darling Basin and irrigated agriculture in the region is developing rapidly (Bryan and Marvanek 2004). Irrigated areas are not considered in this study. Rather, we concentrate largely on the dryland parts of the Corridor and on the flood plain. Dryland agriculture is dominated by livestock grazing, particularly sheep grazing, and cereals such as wheat and barley, with some smaller areas of oilseeds and legumes (Bryan and Marvanek 2004). Dryland agriculture tends to be of lower value per hectare than irrigated agriculture, especially horticulture. Approximately 80,000 people reside in the Corridor, with major centres presented in Figure 1. Other important industries such as recreation, tourism and manufacturing also flourish in the Corridor.

The Corridor is important from a geographic perspective because it encapsulates the South Australian length of the River Murray. The River Murray is an important source of water for Adelaide (approximately 1.1 million people) and many rural South Australian towns. Land use and natural resource management in the SA River Murray Dryland Corridor is especially important because of the linkages between dryland and riverine systems.

Natural resource management in the Corridor is coordinated and administered by the Integrated Natural Resource Management Group for the South Australian Murray-Darling Basin Inc. (SA MDB INRM Group). The SA MDB INRM Group was formed by the South Australian Government and includes representatives from various groups involved in natural resource management within the region. The Group administers funds from the NHT and NAP programs. Much of the on-ground NRM works in the Corridor are undertaken by Local Action Planning Groups and individual landholders. The principal means of distributing NRM funds for on-ground works is through direct payments in a devolved grant scheme.

4. Resource Condition Targets and NRM Actions in the Corridor

The linkages between resource condition targets and natural resource management actions are complex. Different natural resource management actions address different resource condition targets. For example, revegetation for biomass may reduce wind erosion, salinity and carbon but not enhance biodiversity. Additionally, different resource condition targets may be achieved through one or more NRM actions. For example, biodiversity may be addressed through revegetation of local native species and vegetation management but not revegetation for biomass production or fodder crops. Resource condition targets, NRM actions and their linkages are summarised in Table 2. This section describes each of the resource condition targets and natural resource management actions in more detail and discusses the linkages between them.

Resource Conditions	**Addressed by NRM Actions**
1. Salinity	1, 2, 3, 4
2. Wind Erosion	1, 2, 3, 4
3. Biodiversity	3, 4
4. Carbon	1, 3
NRM Actions	**Addresses Resource Conditions**
1. Revegetation of Biomass	1, 2, 4
2. Revegetation of Fodder	1, 2
3. Revegetation of Local Native Species	1, 2, 3, 4
4. Vegetation Management	1, 2, 3, 4

Table 2 – Resource conditions and natural resource management actions and their linkages.

4.1. Salinity

Predictions have been made that if current trends are followed “Adelaide’s drinking water from the Murray River will be too salty to drink two days out of five by 2020” (ACF *et al*. 2004). Understandably, there is significant government and community interest in reversing this trend. South Australia has a responsibility to meet salinity targets under the Murray Darling Basin Salinity Management Strategy (MDBC 2001).

It has been documented that a substantial proportion of the salt contribution to the River Murray originates from the dryland areas of the South Australian River Murray Corridor (Barnett *et al*. 2002). The projected increase in salt contribution has been estimated at 82 EC at Morgan (MDBMC 1999) and later revised down to 30 EC at Morgan (Barnett and Yan 2004) over a timeframe of around 100 years. The salt contribution has been enhanced by the widespread clearance of native vegetation and the subsequent increase in recharge and intrusion of saline groundwater into the river (Cook *et al*. 2004, Figure 5). The idea that widespread revegetation of deep rooted perennials may be able to reverse this effect was the main driver for this study. Recently, Cook *et al*. (2004) provide new estimates for recharge rates in the Corridor based on empirical data and this data has been used to update salinity models. Recent studies have shown that the salinity benefits of revegetation in the Corridor may be limited (Barnett and Yan 2004).

Figure 5 – Dryland agricultural landscape near Loxton. The removal of deep-rooted perennial native vegetation and replacement with shallow rooted cereal crops has led to increased groundwater recharge an saline discharge to the River Murray. Farming practices may also increase the exposure of soils to wind erosion.

In this study we quantify the river salinity benefits achieved by revegetation in the dryland areas of the Corridor in the light of the latest SIMPACT modelling results. The salinity driver of large scale revegetation of perennials is reassessed in the light of these results both in terms of the actual amount of river salinity benefits achieved through revegetation in the dryland areas and the avoided costs to downstream users of the salinity reduction.

Land clearance has increased the salt load contribution from the dryland areas of the Corridor. The removal of deep-rooted perennial native vegetation leads to greater leaching of salts from the soil profile, an increase in saline groundwater recharge and base flow, and an increase in the delivery of salt load to the river. Groundwater in the SA Murray-Darling Basin is saline and travels towards the River Murray as base flow and is discharged directly into the river. This process has been well documented in the SA River Murray (Cook *et al*. 2004).

Revegetation of high salinity benefit areas of the Corridor with deep-rooted perennial species was considered to have the effect of eliminating recharge and, over time, eliminating the salt contribution to the river from the revegetated localities. Any deep rooted perennial species is considered to effectively eliminate groundwater recharge and hence the salt load contribution including the revegetation of saltbush for fodder, eucalypts for biomass or local native species for biodiversity. There are no specific resource condition targets in the Investment Strategy that address the reduction in river salinity through revegetation in dryland areas. However, revegetation can assist in achieving the three river salinity resource condition targets which are listed below (as numbered in INRM Group (2003c)):

7. By 2020, have salinity of water in the River Murray less than 800 EC for 95% of the time at Morgan to ensure drinking water standards

8. By 2020, have salinity of water in the River Murray less than 543 EC for 80% of the time at Berri Irrigation Pump Station to ensure drinking water standards
9. By 2020, have salinity of water in the River Murray less than 770 EC for 80% of the time at Murray Bridge Pump Station to ensure drinking water standards

This study furthers research into achieving the salinity resource condition targets by integrating and extending previous work assessing the salinity benefits of revegetation in the dryland areas of the River Murray Corridor. We also assess the feasibility of revegetation for achieving salinity benefits. Salinity mitigation is an objective in systematic regional planning for multiple objective NRM in the Corridor. Geographic priorities for revegetation are identified that address salinity objectives as well as other resource condition targets of wind erosion and biodiversity.

4.2. Wind Erosion

Soils in the Corridor have varying levels of susceptibility to wind erosion according to the level of clay content in the soil profile. Sandy soils of low clay content are common and tend to have an inherently higher susceptibility to erosion by wind. Land clearance has exacerbated the problem of wind erosion on susceptible soils. Land clearance involves the removal of deep-rooted perennial native vegetation and replacement with shallow-rooted annual crops and pastures. Removal of the soil-binding action and wind speed mitigation provided by deep-rooted perennials increases the risk of soil erosion (see Figure 5). In addition, there are localised areas of long term actively eroding land in the Corridor. Thus, there are two forms of wind erosion of interest for natural resource management in the Corridor. For the purposes of this study it is assumed that any type of deep-rooted perennial vegetation will mitigate soil wind erosion through the permanent soil-binding action of the root systems and the improved protection of the soil from wind exposure. The resource condition target relevant to wind erosion in the SA River Murray Corridor is (INRM Group 2003c):

18. By 2020, reduce the area of agricultural land at risk of wind erosion during June each year by 40%

Mitigation of wind erosion is an objective in systematic regional planning for NRM in the Corridor. Geographic priorities for revegetation are identified that target high wind erosion potential areas as well as the other resource condition targets of salinity and biodiversity.

4.3. Biodiversity

Biodiversity includes diversity in genes, species, communities and ecosystems. The diverse physical environments of the Corridor have given rise to high levels of regional biological diversity. Ecosystems include dry and desertic rangelands, grasslands and chenopod shrublands, dune ecosystems, mallee and woodland, and wetland ecosystems of the flood plain. Kahrimanis *et al*. (2001) provide a detailed assessment of the biodiversity of the SA MDB and identify numerous ecological values and threats affecting the Corridor.

Terrestrial and wetland/riverine ecosystems have both experienced biodiversity decline but for very different reasons. Floodplain, wetland and riverine ecosystems have been degraded by changes to environmental flows resulting from river regulation, and invasion by introduced species. However, in this study we are concerned mainly with terrestrial biodiversity.

Land clearance and agricultural development have been the main contributors to the degradation of terrestrial biodiversity in the Corridor. These processes have led to reduced populations of native plants and animals through both direct habitat removal and indirect population responses to fragmentation. Several species of plant and animal have disappeared altogether from the region and several more are now threatened with extinction (Kahrimanis *et al*. 2001). Thus, Kahrimanis *et al*. (2001) rate the loss of native vegetation as the greatest threat to native biodiversity in the region.

However, several other processes threaten biodiversity in the dryland parts of the Corridor. Over-grazing of remnant vegetation by livestock is the next most serious threat after direct habitat loss and fragmentation (Kahrimanis *et al*. 2001). Livestock grazing changes plant community composition and structure through the removal of understorey species and the prevention of natural regeneration. Other threatening processes include invasion by pest plant and animal species such as rabbits, goats, and foxes. These species compete with native species for resources or directly predate upon native species.

Kahrimanis *et al*. (2001) recognise that a comprehensive biodiversity plan needs to include actions that address all of the processes threatening biodiversity in the Corridor and surrounding regions. In this study we focus on setting priorities that address the most serious threat to biodiversity identified by Kahrimanis *et al*. (2001) – that of native vegetation loss. The resource condition targets for biodiversity in the Corridor that we focus on in this study include (as numbered by INRM Group 2003c):

22. By 2020 improve or maintain condition of terrestrial native vegetation focusing on identified priority areas and improve condition of 50% of remnant vegetation on private land as well as increasing vegetation cover by 1% in the agricultural region.
23. Maintain and improve the conservation status of all threatened National and State listed species and regionally threatened communities and species by 2020.

In addressing these resource condition targets, revegetation of biomass or fodder species are not considered to have any biodiversity benefits as they are typically monocultures and are either periodically harvested or grazed by livestock. Commercial revegetation involves the broadacre planting of a monoculture (e.g. giant mallee (*Eucalyptus oleosa*) for biomass or old man saltbush (*Atriplex nummularia* Lindl.) for fodder). In this study, we consider both vegetation management for the maintenance of biodiversity on private land, and revegetation of local native species for the restoration of native habitat. We identify the geographic priorities for both vegetation management and revegetation of local native species for biodiversity according to well established conservation principles adapted to existing spatial data of biological resources. Other NRM objectives of salinity and wind erosion are also considered along with biodiversity.

4.4. Carbon

Carbon is an emerging priority in natural resource management. Carbon dioxide accumulation in the Earth's atmosphere is one of the major factors behind the enhanced greenhouse effect and associated climate change. Under the Kyoto protocol, signatories have committed to a 5.2% reduction in their collective greenhouse gases compared to the year 1990, calculated as an average over the years 2008 – 2012. Different countries have different reduction targets due to the nature of their economies. Australia's target is an 8% increase on 1990 levels. If signatories wish to increase their emission beyond their target they need to buy carbon credits to offset this increase. However, Australia has not ratified the Kyoto protocol and as a result, any carbon sequestration offsets achieved in Australia are not recognised under the protocol. As such, the ability of Australia to participate in the global carbon market is limited, until it is ratified. However, Australia has signed a greenhouse agreement with the US in which it commits to emission targets. The government has been criticised for limiting its carbon trading market to the US.

The revegetation of cleared landscapes sequesters carbon from the atmosphere. Significant interest exists in Australia in revegetation for carbon sequestration with a view to future participation in a global carbon market. New South Wales and Victoria are in the process of setting up carbon markets with tradable property rights in anticipation. There has also been substantial interest in the purchase of carbon credits from large-scale Australian revegetation projects from international corporations. Media reports claim that “NSW has already engaged in international carbon trades with a Swiss-Italian electronics company and a Tokyo power utility, but their trades will not be recognised by Kyoto while Australia remains outside the system” (Lane 2004).

Technically, any revegetation done since 1990 is eligible to be traded as carbon credits. Clearly, the larger and faster growing the species and the more productive the climate, the more carbon able to be sequestered. Very recent results from Hobbs and Bennell (2005) suggest that a short cycle eucalypt plantation can sequester between 2.5 and 4.2 tonnes of carbon per hectare per year in the Corridor depending on the climate.

This figure does not include two other important aspects which may contribute to carbon credits. Firstly, mallee species grow a large woody lignotuber underground which acts as a carbon reservoir. Thus, much of the carbon storage of mallee biomass species is underground and any carbon accounting of mallee biomass species must consider this. Secondly, where carbon sequestration replaces grazing as a land use, there may also be carbon offset benefits involved in reducing livestock numbers and associated methane production.

At the time of writing (23.03.05) carbon is trading at €14.85 per tonne on the European market and has doubled in price over the past 2 months. Thus, based on the Hobbs and Bennell (2005) productivity figures alone, potential benefits from carbon credits from eucalypt plantations in the Corridor range between $50 and $105 per hectare per year in today’s market. In perspective, this level of economic return is substantially greater than livestock grazing and is comparable with cereal cropping. Eucalypts are also likely to be more resilient to potential climate change than traditional forms of agriculture.

Carbon credits may be integrated with biomass production. The major area of discordance is that the biomass is burned during processing for electricity and the carbon is released back into the atmosphere. Thus, apart from the subsurface storage, the carbon sequestration involved in biomass production is a zero sum game. However, the production of clean electricity through biomass offsets the need to burn coal to produce electricity. For example, Howard and Olszak (2004) state that on average, 1.363 tonnes of CO_2 is produced per megawatt hour of electricity production in Victoria. Typical electricity production from a 5 MW ITP plant is approximately around 40,000 MWh/yr (Enecon 2001) which would offset about 55,000 tonnes of CO_2 per year. At today’s prices, this amounts to $1,375,000 AUD in carbon credits per year. This benefit is currently accounted for under the Renewable Energy Credits scheme in Australia which provides payments at a rate of around $40 per Megawatt.

The revegetation of local native species is ideally suited for carbon trading. The revegetated stands must remain in perpetuity for carbon trading, which suits biodiversity goals because communities have the chance to undergo natural successional processes. The restored community has biodiversity benefits and an income may be generated from carbon trading. Different community types are able to sequester different amounts of carbon per hectare. Whilst, revegetation of local native species for biodiversity may have lower productivity rates than those used in the calculations above, the total carbon sequestration could still be significant.

A conservation reserves established after 1990 are eligible for carbon credits under the Kyoto protocol it may also be possible that vegetation management activities could attract carbon credits. However, revegetation of fodder crops such as saltbush are unlikely to attract significant carbon credits because of the low productivity of the species. However, this needs more research.

There are several obstacles to landholders undertaking revegetation for carbon trading, specifically:

- There are significant upfront establishment costs, maintenance and opportunity costs;
- There is some uncertainty about the market for carbon especially given that Australia has not ratified the Kyoto protocol;
- Trading rules and standards could change at any time.

Carbon trading was not pursued further in this study because at the time this research was designed and conducted the level of return per hectare combined with the obstacles to trade meant that it was not likely to be a viable option at the time. The carbon trading landscape has changed dramatically since then. Carbon has emerged as a potentially viable option mainly as a result of a doubling in both the estimates of carbon production in the Corridor and the European market price of carbon. Carbon trading has increasing potential as an economic driver capable of encouraging the large scale land use changes required to achieve NRM targets in the Corridor and elsewhere. Carbon credits can be integrated into a biomass industry and/or revegetation for biodiversity program and would significantly enhance the success of these programs. However, whilst the viability of carbon trading has increased, the barriers to trade still persist and will need to be addressed if carbon trading is to be adopted on a broad scale. More research is required to design policy based on carbon trading that encourages NRM actions in high priority locations and assess factors affecting uptake and impacts (Wang and Medley 2004).

4.5. Remnant Vegetation Management

Achieving biodiversity resource condition targets also requires vegetation management actions on a large scale. Vegetation management includes the removal of threatening processes from remnant vegetation patches (i.e. stock exclusion), as well as weed removal and reintroduction of local native species in degraded remnants (Figure 6). The location of vegetation management actions is important to provide the greatest benefits to regional biodiversity. Conservation principles can be used to identify regional geographic priorities for vegetation management. For example, we may seek to make sure that a certain percentage of each climate zone, soil type and vegetation community is managed. We may want to manage a certain proportion of rare and threatened species habitat. Landscape ecological principles also say that we want to concentrate our efforts on the largest, most well connected, least fragmented and most simply shaped patches (Fahrig 2003).

Figure 6 – Remnant mallee community east of Blanchetown (Photo T.E. Schultz 2004).

Figure 7 – Remnant grassy chenopod shrubland community east of Swan Reach (Photo T.E. Schultz 2004).

The systematic regional geographic priorities identified for vegetation management in this study are also intended as a guide for regional policy and need to be interpreted and adapted to actions on a local scale. Regional geographic priorities need to be converted into on-ground actions in specific locations by local landholders. This includes implementing vegetation management actions such as stock exclusion from specific areas in the landscape and engaging in other supporting management actions such as weed removal as dictated by local conditions. Guidelines for the management of native vegetation also exist (e.g. PIRSA 2001) and these provide appropriately detailed information for landholders to implement on-ground vegetation management actions.

4.6. Revegetation of Local Native Species

Revegetation has the potential to assist the conservation of biodiversity in agricultural areas (Hobbs 1993). Revegetation to improve biodiversity should involve a complex suite of indigenous canopy and understorey flora. Native communities must be re-established in geographic priority areas for the greatest regional biodiversity benefit. Geographic priority areas can be identified according to a number of well established conservation principles such as representativeness and landscape ecological principles such as area, connectivity, fragmentation and shape (Saunders *et al*. 1991, McIntyre and Hobbs 2000, Bryan 2003, Fahrig 2003, Crossman and Bryan in review).

The regional geographic prioritisation of revegetation for biodiversity examined in this study provides a systematic way of ensuring regional resource condition targets are met in the most cost effective way. The geographic priorities identified in this study are aimed at guiding regional INRM policy and subsequent distribution of funds for revegetation for biodiversity, rather than to prescribe the species and communities to be established in the precise locations in the landscape. The systematic regional geographic priorities are too broad in scale to guide local revegetation efforts on the ground. Priority areas need to be interpreted and adapted on a local basis with high resolution geographic information and combined with local knowledge. Many excellent guides to revegetation for biodiversity exist that have been prepared for the Local Action Planning groups in the region (Bennett 1994, Good 1994, Creation Care 1999a, 1999b, 1999c, 1999d, Murray Mallee Local Action Planning Association Inc. 2001, PIRSA 1999, 2001). These guides contain detailed information about revegetation and the reconstruction of native habitat for biodiversity purposes suitable for on-ground application by landholders. They cover issues such as seed sources, how to determine species mixes and community structure for specific sites. In addition, revegetation of local native species needs to occur in conjunction with other actions that enhance biodiversity conservation such as stock removal and pest plant and animal control. These processes occur on a scale that is impossible to consider as part of systematic regional planning and need to be guided by fine scale local on-ground knowledge.

4.7. Revegetation of Biomass

Large-scale revegetation of deep-rooted perennials is required to meet resource condition targets in the Corridor. The benefits of these actions are largely public and the costs of which in terms of time and effort are considerable. Revegetation is required largely on private land and the incentives for private landholders and community groups to undertake such a task do not currently exist. Market-based policy initiatives such as biomass industries have the potential to encourage the scale of revegetation necessary. Bennell *et al*. (2004) investigated a range of economic options for the large scale planting of deep-rooted perennials across the low rainfall areas of southern Australia. Options investigated by Bennell *et al*. (2004) include pulpwood production, fibre and particle board, bioenergy, *Eucalyptus* oil and fodder crops. Broadacre planting of *Eucalyptus* species for bioenergy and oil, and fodder crops for grazing, were identified as the best options for the Corridor (T. Hobbs, Cooperative Research Centre for Plant-based Management of Dryland Salinity, pers. comm. 2004).

Revegetation for biomass industries in the Corridor, in particular, the supply of feedstock to an Integrated Tree Processing (ITP) plant, involves the planting of mallee species at a density of between 1,000 and 2,500 trees per hectare. The most suitable species for such a purpose is likely to be *Eucalyptus oleosa* (T. Hobbs, pers. comm. 2004). Plants have an establishment phase of up to six years until first harvest and the optimal harvesting regime is every three years after that. At harvest, the trees are coppiced near ground level and reshoot from rootstock. Green biomass is then transported to the plant where it is processed for renewable energy, oil and activated charcoal.

This process has been subject to significant research interest (Enecon 2001, Howard and Olszak 2004) and a trial 1 MW plant is currently operational in Narrogin, Western Australia. This demonstration plant is currently processing 20,000 tonnes of green biomass per year and produces 7,500 MWh/yr of electricity (enough electricity to power 1,000 homes). Production of biomass by farmers in WA has the complementary natural resource management benefit of mitigating dryland salinity caused by land clearance and agricultural development. The Narrogin trial has demonstrated the viability of the concept. The Oil Mallee Company who had a major role in supply of feedstock to the plant suggests that there is the potential for 10 ITP plants, each 5 times the size of the existing Narrogin demonstration plant in south west WA.

Conversion of productive agricultural land to deep-rooted perennials on a large scale is expensive because of the high opportunity costs of forgone agricultural production and establishment and maintenance costs. Bennell *et al*. (2004), Ward and Trengove (2004) and Connor and Bryan (2005) investigated market-based opportunities to encourage large-scale revegetation in the Corridor. The focus of these studies was the commercial production of eucalypts for production of electricity, activated charcoal and oil by an ITP plant. Bennell *et al*. (2004) and Ward and Trengove (2004) found that growing eucalypts for biomass is at least comparable, if not better, in economic terms to existing agricultural production summarised by Sadras (2004). Ward and Trengove (2004) also found that ITP plant operation may also be a viable enterprise in the Corridor (see also SKM 2001). Biomass species also have wind erosion benefits due to their stabilising effect on the soil and carbon benefits from production of renewable energy. However, eucalypt monocultures grown for biomass are considered in this study not to have biodiversity benefits. In this study we conduct a detailed spatial and economic analysis of a biomass industry in the Corridor to assess the potential of this market-based mechanism for encouraging large-scale revegetation of deep-rooted perennial species in the Corridor.

4.8. Revegetation of Fodder Crops

The production of perennial fodder crops of old man saltbush (*Atriplex nummularia*) has shown economic potential in the Corridor (Bennell *et al*. 2004). Fodder crops are an economically viable deep-rooted perennial species capable of achieving NRM objectives such as salinity reduction and wind erosion mitigation. Fodder is often thought of as a *standing haystack* because of its typical agricultural usage as a supplementary stock feed. Therefore it is financially viable for use on existing grazing land. There are usually few opportunity costs because, apart from the establishment phase, the farmer does not have to remove stock from the land. There may be a positive gain in stocking rates because of the increase in supply of feed. For the purposes of this study, fodder crops are considered to reduce recharge and the resultant salt load contribution to the river, and mitigate wind erosion on susceptible soils. However, they are considered not have biodiversity nor carbon benefits for the purposes of this study. The broadacre planting of fodder crops is the most common form of revegetation of deep-rooted perennials in the Corridor undertaken to date

(Figure 8). As the NRM action of revegetation of fodder crops is known to be economically viable, it is not quantitatively assessed in systematic regional planning in this study. Revegetation of fodder can be thought of as a reliable fallback NRM action that can be used to address both salinity and wind erosion in areas that are currently grazed.

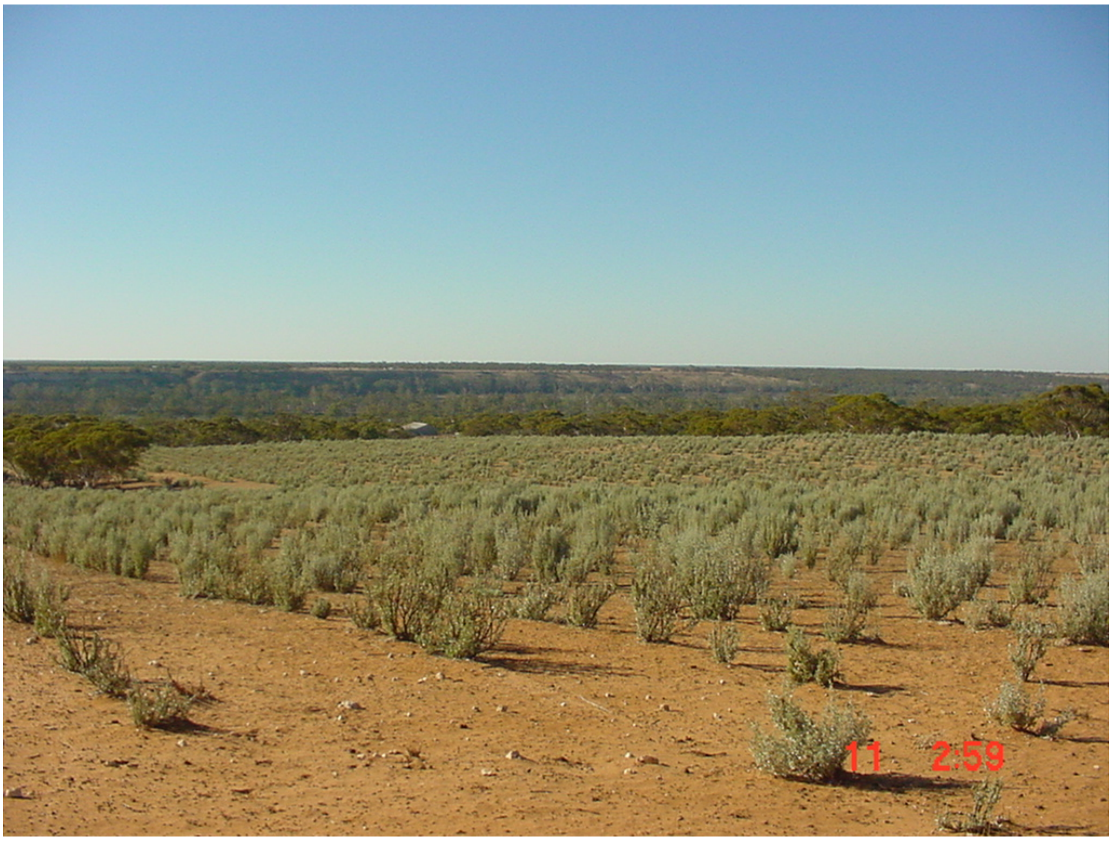

Figure 8 – Old Man Saltbush fodder crop plantation near Waikerie (Photo T. E. Schultz 2004).

5. Analysis

In this section we present the methods and results of systematic regional planning for multi-objective NRM in the River Murray Corridor. The spatial multi-criteria decision analyses are presented and the geographic priorities for vegetation management, revegetation of local native species, and revegetation of biomass that most cost effectively address regional resource condition targets are assessed. We follow the steps outlined by Malczewski (1999) and described in Section 2.2. The MCDA is very much a spatial analysis. Much of the analysis is centred on the development of *attribute* or criteria layers for input into the MCDA. The decision rules of the MCDA use an integer programming spatial optimisation model to solve the multi-objective decision problem. Attribute layers are included in spatial optimisation either as part of the objective function where they can be minimised or maximised, or as constraints where targets can be set.

The problem is defined below:

At the highest level, we want to identify cost-effective ways of achieving the following major resource condition targets:

- 50% of remnant vegetation on private land is managed
- 1% of native habitat is restored on cleared land

In addition, other targets involving salinity and wind erosion are also adapted and operationalised from the resource condition targets stated in the Investment Strategy (NRM Group 2003c) and are described in detail in the relevant sections below.

Resource condition targets can be met by identifying geographic priorities for the following NRM actions:

- Management of remnant native vegetation
- Revegetation of local native species for biodiversity
- Revegetation of biomass species

5.1. Preliminary Analyses and Assembly of Evaluation Criteria Layers

A significant part of spatial MCDA is the generation of the *criteria* or attribute layers for input into the decision analysis. Attribute layers are GIS-based data layers that describe the spatial distribution of each decision criteria. In this study we use a raster data structure based on grid cells of 254 m resolution (6.4516 ha). Creating attribute layers can involve an array of GIS-based spatial process modelling techniques depending on the nature of the attributes modelled. The attribute layers include the salinity layers, biodiversity layers, biomass layers, wind erosion layers, and the opportunity cost layer. The methods and results of developing these layers are presented below. Often the generation of attribute layers is a distinct study in itself with useful results that provide insight for the policy process.

5.1.1 Salinity

One policy option that has potential in the Corridor is the payment of landholders for public salinity benefits of revegetation as part of a salinity credit system (Ward and Connor 2004). A logical payment amount for salinity is the cost of salinity to downstream users avoided by revegetation through recharge reduction. To calculate the spatial distribution of the cost to downstream users we use outputs from SIMPACT that characterise the total salinity benefits for the River Murray achieved through revegetation in the dryland areas in kg/ha/yr. These are converted to units of Electrical Conductivity (EC) at Morgan and the total present value of avoided costs to downstream users is calculated. A time frame of 100 years is used in this study to conform with the time frames used by the MDBC's salinity register. The magnitude of the benefits of revegetation in dryland areas for river salinity is reassessed and geographic priorities are identified for revegetation to achieve salinity resource condition targets for NRM.

SIMPACT is an established model originally developed to assess the impact of new irrigation developments on the salinity of the River Murray. SIMPACT is a GIS-based model that uses spatial data describing several biophysical parameters to calculate the spatial distribution of salinity benefits. Now in its second version, SIMPACT II uses the unsaturated zone method and combines information about drainage rates, depth to groundwater and clay thickness with equations linking subsoil moisture content to estimate recharge over time (Wang *et al*. 2004). The unit response equation (Knight *et al*. 2002) is used to estimate the impact of increased recharge on discharge to the river and this is multiplied by the acquifer salinity at discharge to calculate salt load to the river (Wang *et al*. 2004). SIMPACT II works in a raster GIS environment based on 254m grid cell resolution. A derivative of SIMPACT II – SIMRAT (Fargher *et al*. 2003), has been accredited by the MDBC for assessing the salinity impacts of irrigation developments for charting on the Salinity Register under the MDBC's Basin Salinity Management Strategy.

SIMPACT is also able to characterise the salinity benefits of revegetating dryland areas to the salt load in the River Murray if revegetation is assumed to eliminate groundwater recharge. However, SIMPACT model can only calculate the impact of revegetation on reducing salt loads to the river for those parts of the landscape where recharge to the aquifer is equal to root zone drainage. These are the areas where root zone drainage has *wetted up* the soil and sediments from the roots down to the water table. In general, the areas that have sandy soils and a shallower depth to the water-table are the first to reach this fully wetted up state. Most of the land in the dryland parts of the Corridor not yet reached this state, but will do so over the next 10 to 20 years. Hence, SIMPACT cannot be used to calculate the impacts of revegetation undertaken now on salt loads to the river across most of the Corridor. Whilst revegetation in these areas will have salinity benefits for the River Murray, the current version of the SIMPACT model cannot quantify the magnitude of these benefits. Hence, the SIMPACT estimates of the salinity benefits of revegetation used in this study are conservative.

5.1.1.1 Methods

SIMPACT calculates the salinity benefit of revegetating each grid cell in kg/ha/yr and this information is converted into units of EC at Morgan and used to calculate the costs of salinity to downstream users avoided by revegetating each grid cell. To do this we first need to convert salt load measured in kg/ha/yr (Figure 9) into units of 100s tonnes/cell/day as these are the units required in the conversion process (Figure 10). This is done by multiplying SIMPACT outputs by the area in hectares of each cell (6.4516 ha), then dividing by the number of days in a year (365.25) and 100,000 to convert kg into 100s of tonnes. Note that all operations are conducted in a raster GIS and the values for all grid cells are calculated simultaneously using raster functions within the GIS.

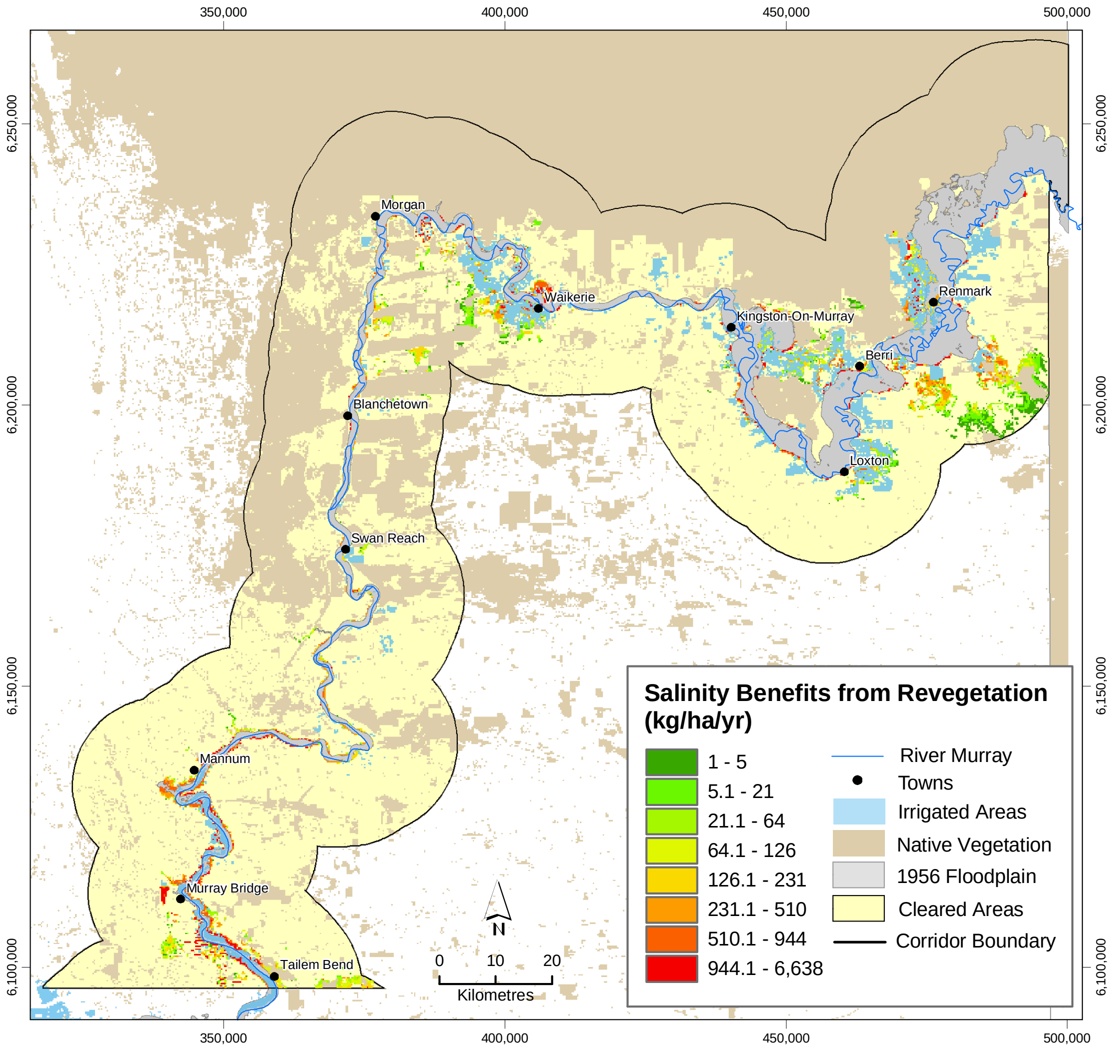

Figure 9 – Salinity benefits of revegetation as output from SIMPACT II in kg/ha/yr.

The conversion is:

$$SL_k = \frac{SIMPACT_k \times 6.4516}{365.25 \times 100{,}000}$$

Where:

SL_k = Salinity benefit of revegetating each grid cell (*k*) measured in 100s tonnes/cell/day

$SIMPACT_k$ = Salinity benefit of revegetating each grid cell (*k*) measured in kg/ha/yr as output by SIMPACT

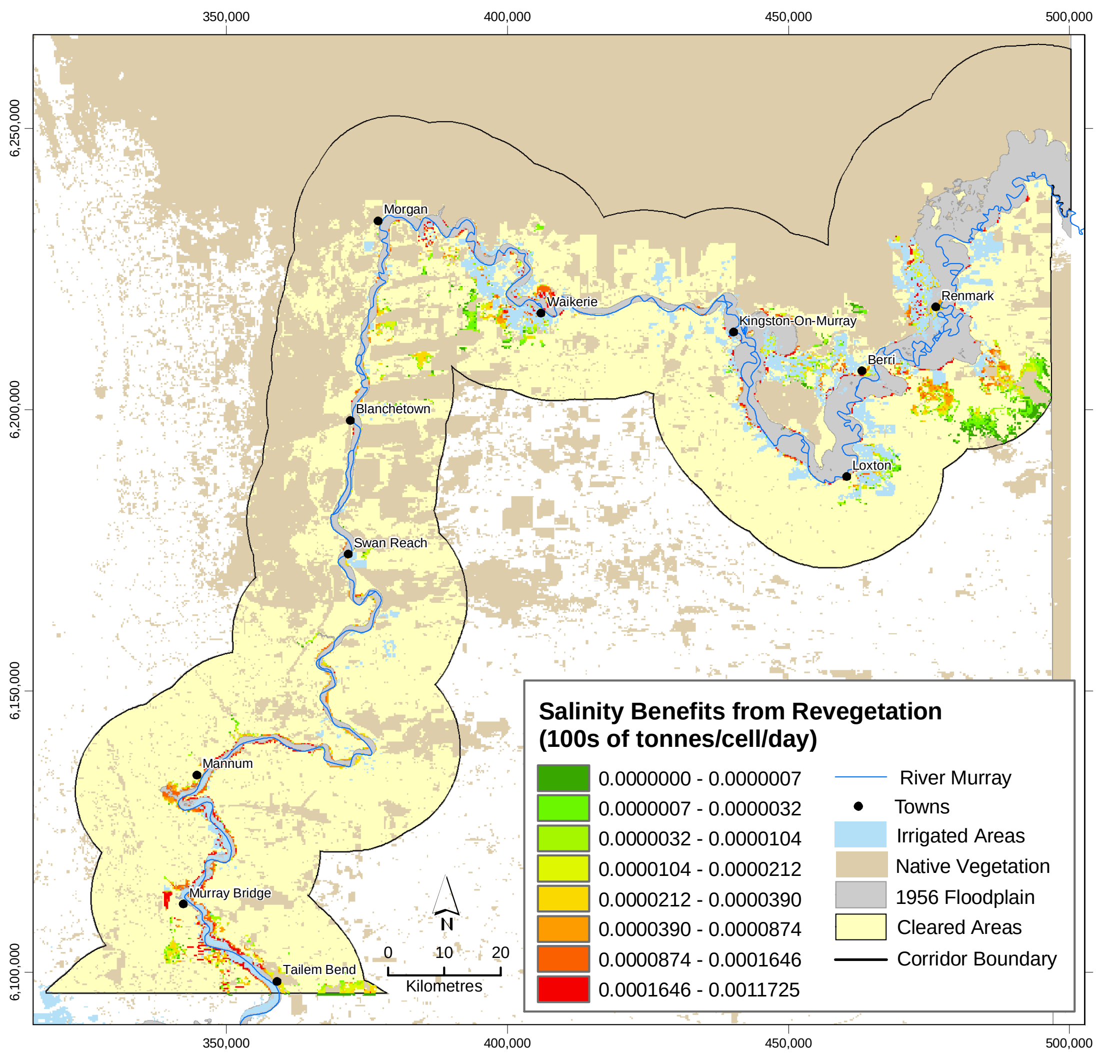

Figure 10 – Salinity benefits of revegetation in 100s of tonnes/cell/day.

Salinity benefits achieved through revegetation do not occur instantaneously. SIMPACT outputs quantify the salinity benefits of revegetation at 2 time slices – 50 and 100 years. We need to model the total salinity benefits occurring each year in order to calculate the total avoided costs to downstream users of salinity over the 100 year time horizon. To determine the salinity benefits (*SL*) of a grid cell *k* at year *t* we consider that:

$$SL_{k,t} = f(t)$$

Where:

$SL_{k,t}$ = Salinity benefits from cell *k* in year *t* in 100s tonnes/cell/day

As we only know the salinity benefits on each cell at t = 50 and t = 100 a bent stick function is used to model the salinity benefits for each grid cell *k* at year *t* such that a linear increase is assumed from year 0 to year 50 and again from year 50 to year 100 (Figure 11):

$$SL_{k,t} = \frac{SL_{k,50} \times t}{50} \quad \text{for } t <= 50$$

$$SL_{kt} = \frac{(SL_{k,100} - SL_{k,50})(t - 50)}{50} + SL_{k,50} \quad \text{for } 50 < t <= 100$$

Where:

$SL_{k,50}$ = Known salinity benefits of revegetating cell *k* in year 50 in 100s tonnes/cell/day

$SL_{k,100}$ = Known salinity benefits of revegetating cell *k* in year 100 in 100s tonnes/cell/day

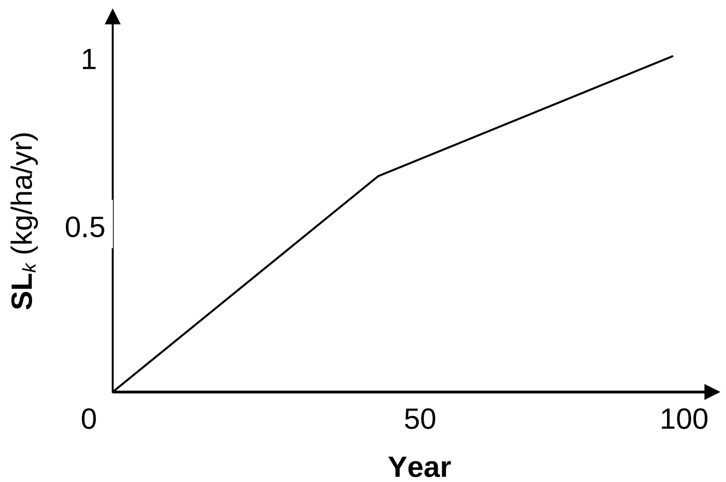

Figure 11 – Example of a bent stick function used to estimate the increasing salinity benefits achieved through revegetation of a grid cell over time. Individual bent stick functions are modelled for each grid cell and may be convex or concave depending on the hydrogeological and geographical disposition of each cell.

The outputs of SIMPACT modelling are then converted into Electrical Conductivity units measured at Morgan (Figure 1) in SA (i.e. ECs at Morgan). This is done to assess the salinity benefits of revegetation in the units used by MDBC salinity targets (i.e. 800 EC at Morgan 95% of the time). Salinity benefits of revegetation output from SIMPACT are converted to units of EC at Morgan using information contained in the Murray-Darling Basin Commission's BigMod Ready Reckoner. This information provides conversion coefficients which convert salt load in 100s of tonnes/cell/day into EC at Morgan at several points in the river at an assumed flow rate of <10,000 ML/day. Conversion coefficients had been converted into GIS by DEH using a linear interpolation of point-based Ready Reckoner data along the river. Dryland grid cells are attributed values under the assumption that groundwater flows from each cell to the nearest point in the river (Figure 12). By multiplying the GIS layers we calculate the total salinity benefits of revegetating each grid cell in EC at Morgan at t = 50 and 100 years as:

$$EC_{k,t} = SL_{k,t} \times ECM_k$$

Where:

$EC_{k,t}$ = Total salinity benefits of revegetation in units of EC at Morgan

t = 50 or 100 years

ECM_k = EC at Morgan conversion coefficient for grid cell k from MDBCs BigMod Ready Reckoner interpolated using GIS

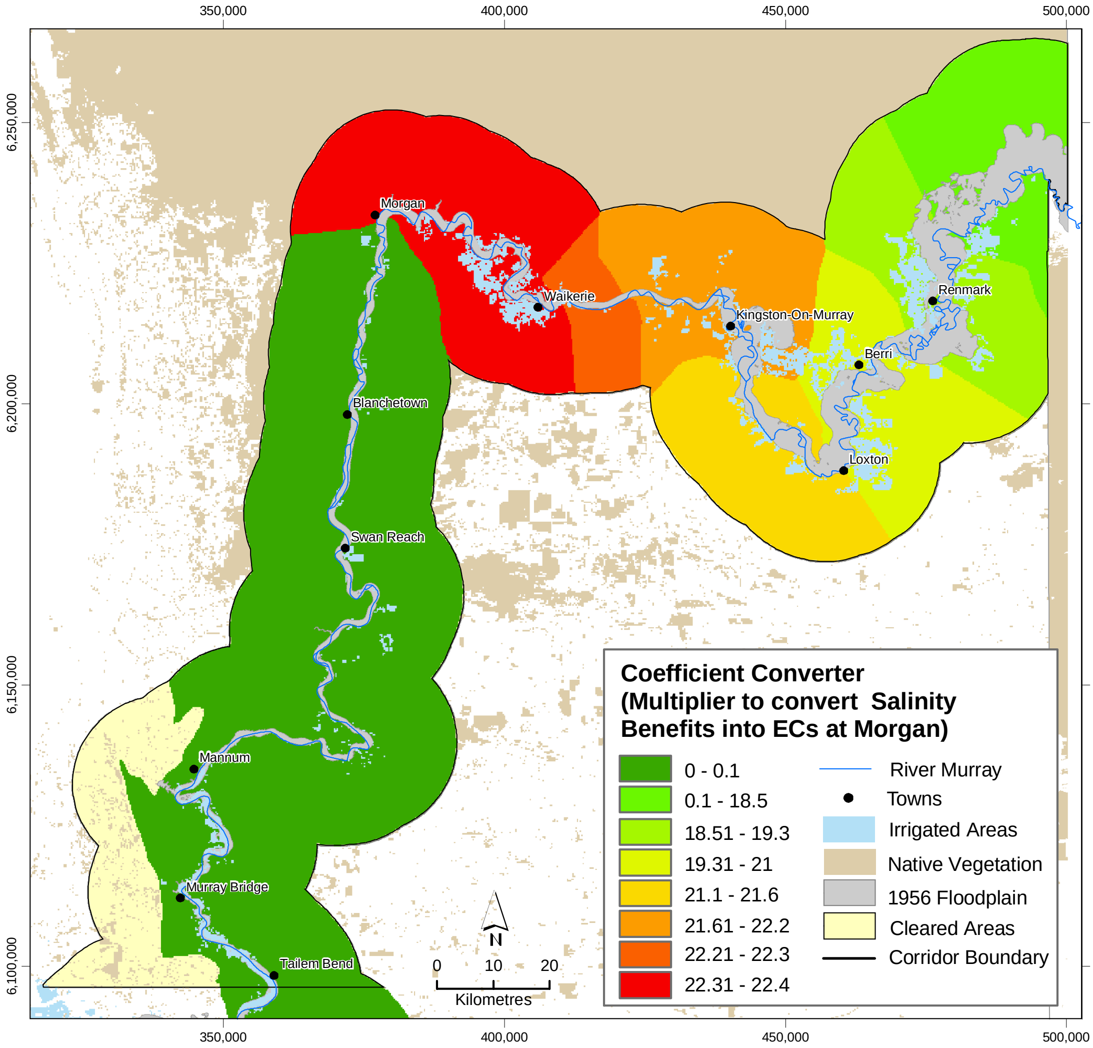

Figure 12 – Interpolated EC at Morgan conversion coefficient layer derived by DEH from the MDBC BigMod Ready Reckoner data which provides multipliers to convert salinity benefits from 100s of tonnes per day into EC at Morgan at flow rates of <10,000 ML/day.

Connor *et al*. (2003) use the avoided costs of salt interception to determine the economic benefits of reduced river salinity resulting from dryland revegetation. We updated the analysis of Connor *et al*. (2003) by calculating the spatial distribution of avoided costs of salt interception of the equivalent amounts of salinity using new salinity benefits data from SIMPACT on a cell-by-cell basis in a GIS environment. However, the costs to downstream users proved to be a more direct measure of the cost of salinity as this measure is used to justify investment in salt interception (Bob Newman, MDBC, pers. comm. 2004). Hence, the results of the avoided costs of salt interception are not presented here but are available from the authors.

We determine the avoided costs of salinity to downstream users achieved by revegetating each grid cell *k* using the SIMPACT salinity benefit outputs and indicative estimates of the costs of salinity to downstream users described by GHD (1999). This is done in a similar way as the calculation of ECs at Morgan. The GHD (1999) figures are also represented in the BigMod Ready Reckoner for flow rates of <10,000 ML/day and include cost coefficients at several points along the river in thousands of dollars per year per 100 tonnes/day. This information has been spatially interpolated and converted to GIS format by DEH (Figure 13). By multiplying the modelled salinity benefits of revegetation of each dryland cell in 100s tonnes/cell/day by the cost to downstream users in thousands of dollars per 100 tonnes of salt per day we arrive at the total cost to downstream users of river salinity avoided by revegetating each grid cell.

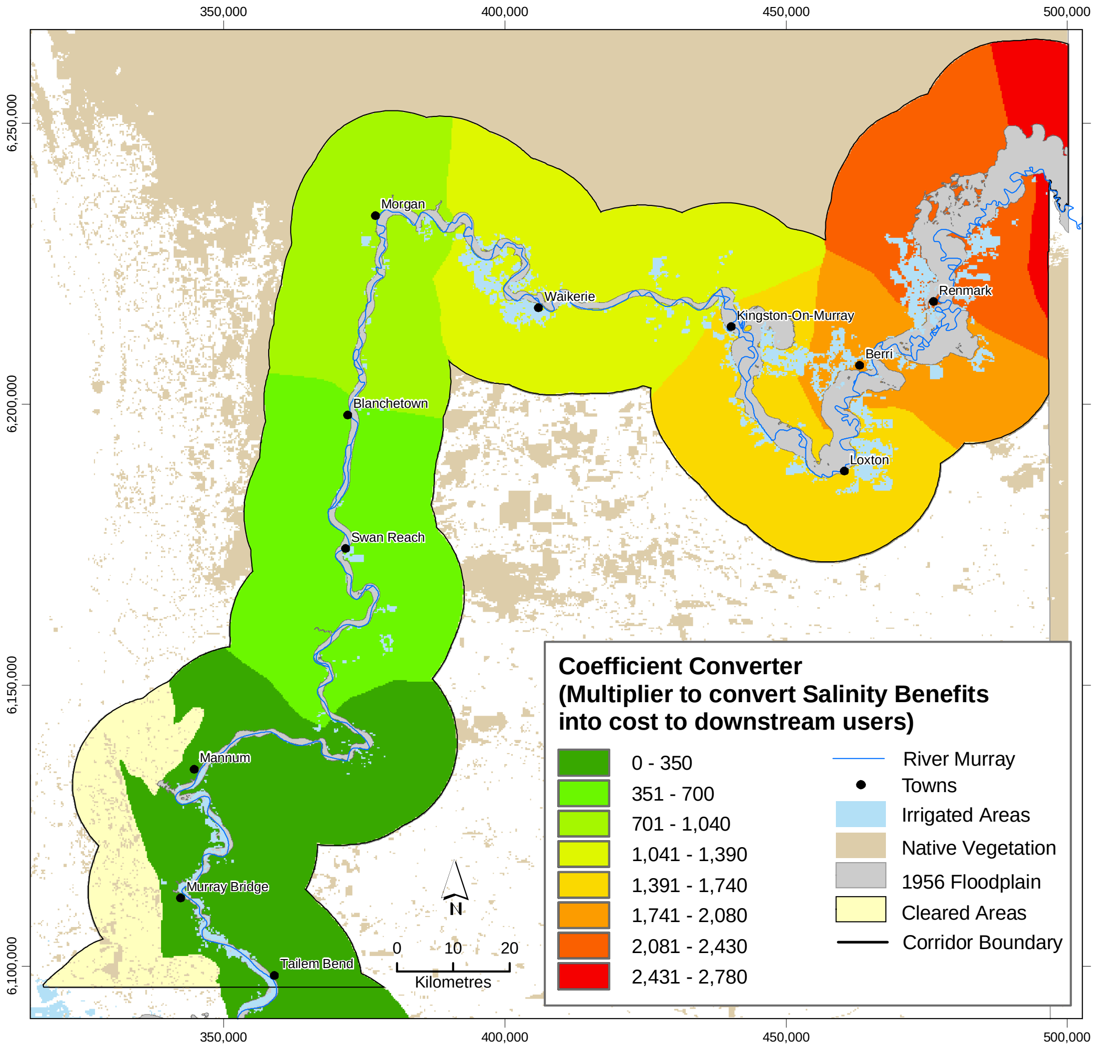

Figure 13 – Interpolated costs to downstream users conversion coefficient layer derived by DEH from the MDBC BigMod Ready Reckoner data which provides multipliers to convert salinity benefits from 100s of tonnes per day into $1,000s of dollars per year in downstream costs at flow rates of <10,000 ML/day.

Using the above information we calculate the total present value of costs of salinity to downstream users avoided by revegetation that can be achieved over a 100 year time period. The total present value of costs of salinity to downstream users avoided by revegetation is calculated as the sum of the yearly costs accumulated over the 100 year time horizon, discounted to presented value terms using a 3% discount rate. The bent stick benefit function is used to calculate the salinity benefit achieved each year for each grid cell. For each year the total cost of salinity to downstream users avoided by revegetating each cell is calculated by multiplying the salinity benefit for that particular year by the cost coefficient and this is converted to present value terms using a social discount rate of 3%. The total present value of costs of salinity to downstream users avoided by revegetation over the 100 year timeframe is the sum of the yearly discounted costs. All this is done iteratively and programmed within a GIS. This is presented mathematically as:

$$PV_k = \sum_{t=1}^{n} \frac{SL_{k,t} \times CC_k}{1000 \times (1+i)^t}$$

Where:

PV_k = Present value of costs ($) to downstream users of river salinity avoided through revegetation for each grid cell (*k*)

CC_k = Cost conversion coefficient (thousands of dollars per 100 tonnes salt per day) for each grid cell (*k*)

i = Interest (discount) rate (3%)

t = Year

n = Number of years = 100

The total present value of costs to downstream users of river salinity avoided by revegetating all dryland grid cells in the SA River Murray Corridor region is calculated by summing the total present value of all dryland grid cells:

$$PV_T = \sum_{k=1}^{m} PV_k$$

Where:

m = Total number of grid cells

5.1.1.2 Results and Discussion

Based on the most recent SIMPACT model outputs, the total salinity benefits of revegetation in the dryland areas is approximately 21.1 tonnes/day or 1.96 EC at Morgan after 50 years, and 41.5 tonnes/day or 4.14 EC at Morgan after 100 years. The nature of the impact of recharge in the cleared dryland areas of the Corridor is that the majority of salinity benefits after 100 years may be achieved by revegetating only 10,000 hectares. Thus, most of the salinity benefits come from only 1.6% of the total dryland area in the Corridor (Figure 14, Figure 15; Figure 16, Figure 17). The total cost to downstream users of riverine salt load avoided by revegetation is just over $3.15 Million in present value terms over 100 years.

The outputs of SIMPACT modelling suggest that a geographically targeted approach is required to encourage revegetation in dryland areas that offer large salinity benefits. The costs of salinity to downstream users avoided through revegetation of the highest salinity benefit grid cells is over $2,500/ha (Figure 14). This decreases rapidly to the point where the total avoided costs tends to zero after the highest 10,000 ha of salinity benefit areas.

Salinity benefits may take many years until full realisation as they tend to occur over long time scales. As a result, the benefits are greatly discounted and there is significant risk surrounding the delivery of these benefits. By comparison, Salt Interception Schemes have much greater certainty surrounding their impact on salt reduction and the impact reaches maximum effectiveness after just a few years of operation. Hence, the investment in revegetation as a means of salinity reduction in the river is not as cost effective as it commands lower returns and there is a high level of risk involved in the investment. The adoption of a salinity credit scheme for encouraging revegetation would probably not justify the costs of design, implementation and administration in the Corridor. It may however, add weight to an integrative NRM policy mix for natural resource management. The cost of salinity to downstream users may provide a suitable guide as to the appropriate level of payment for salinity credits in the Corridor.

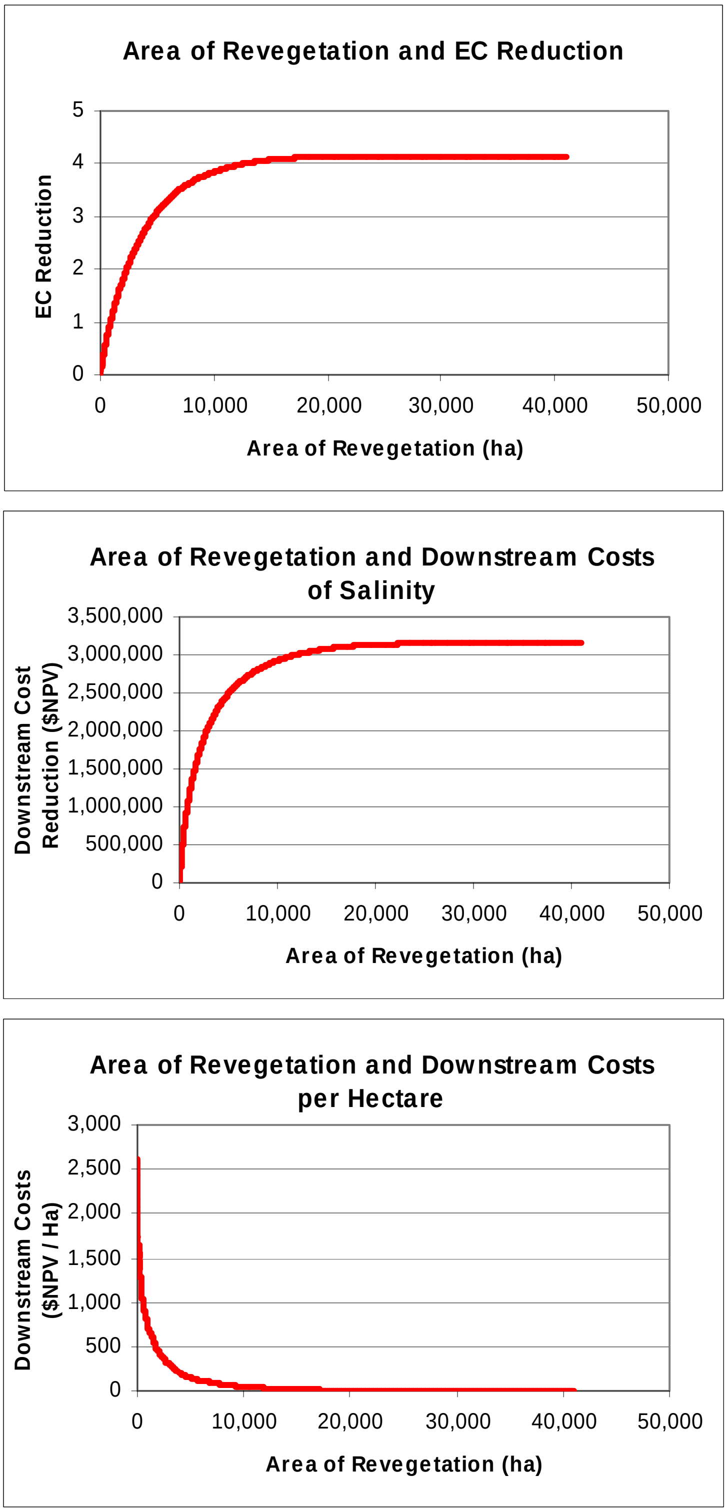

Figure 14 – Relationship between salinity benefits in EC at Morgan after 100 years achieved through revegetation, area of revegetation, and total present value of costs of salinity to downstream users avoided by revegetation. Grid cells are ranked from highest to lowest salinity benefit. Most of the benefit comes from an area of around 10,000 hectares.

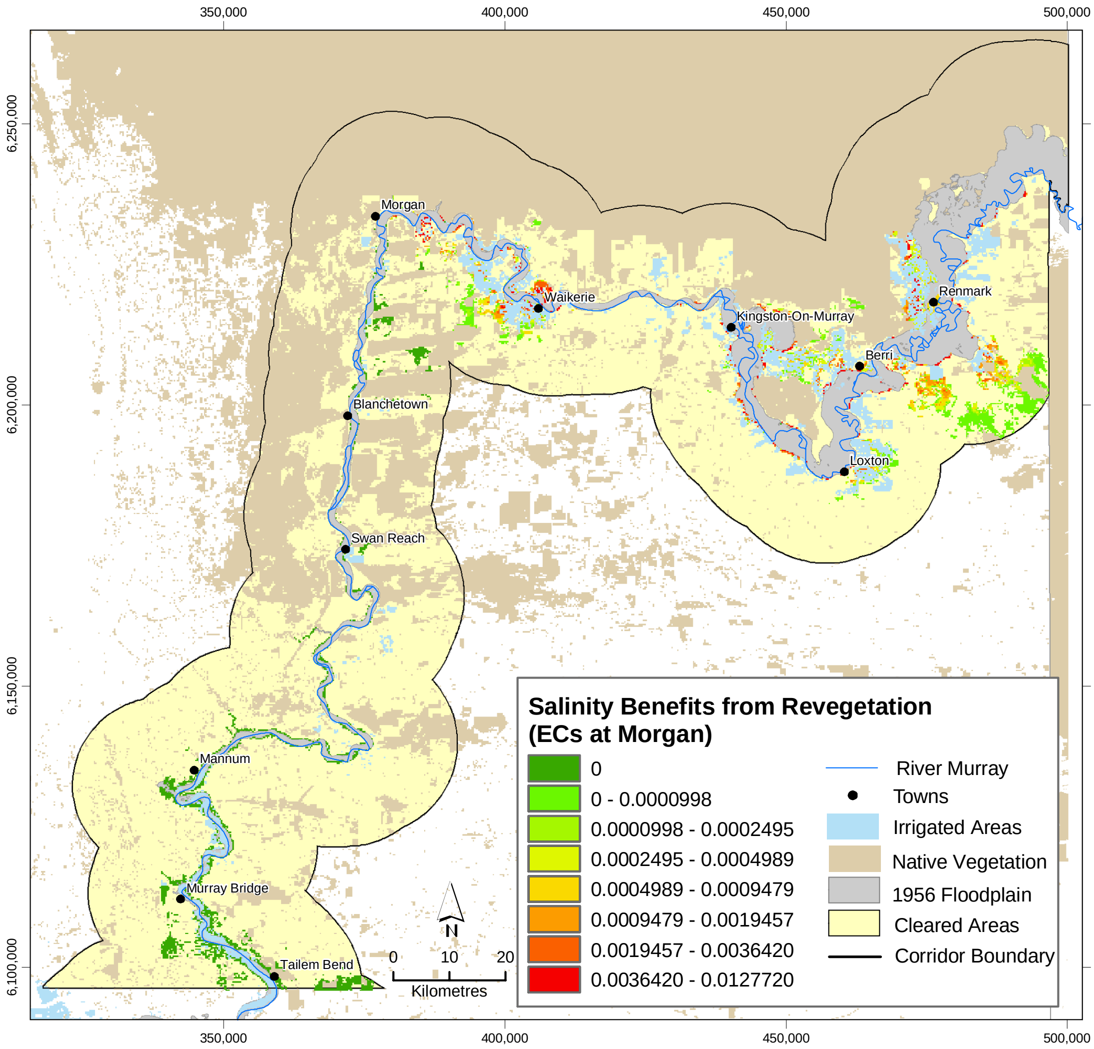

Figure 15 – Salinity benefits from revegetation in units of ECs at Morgan after 100 years.

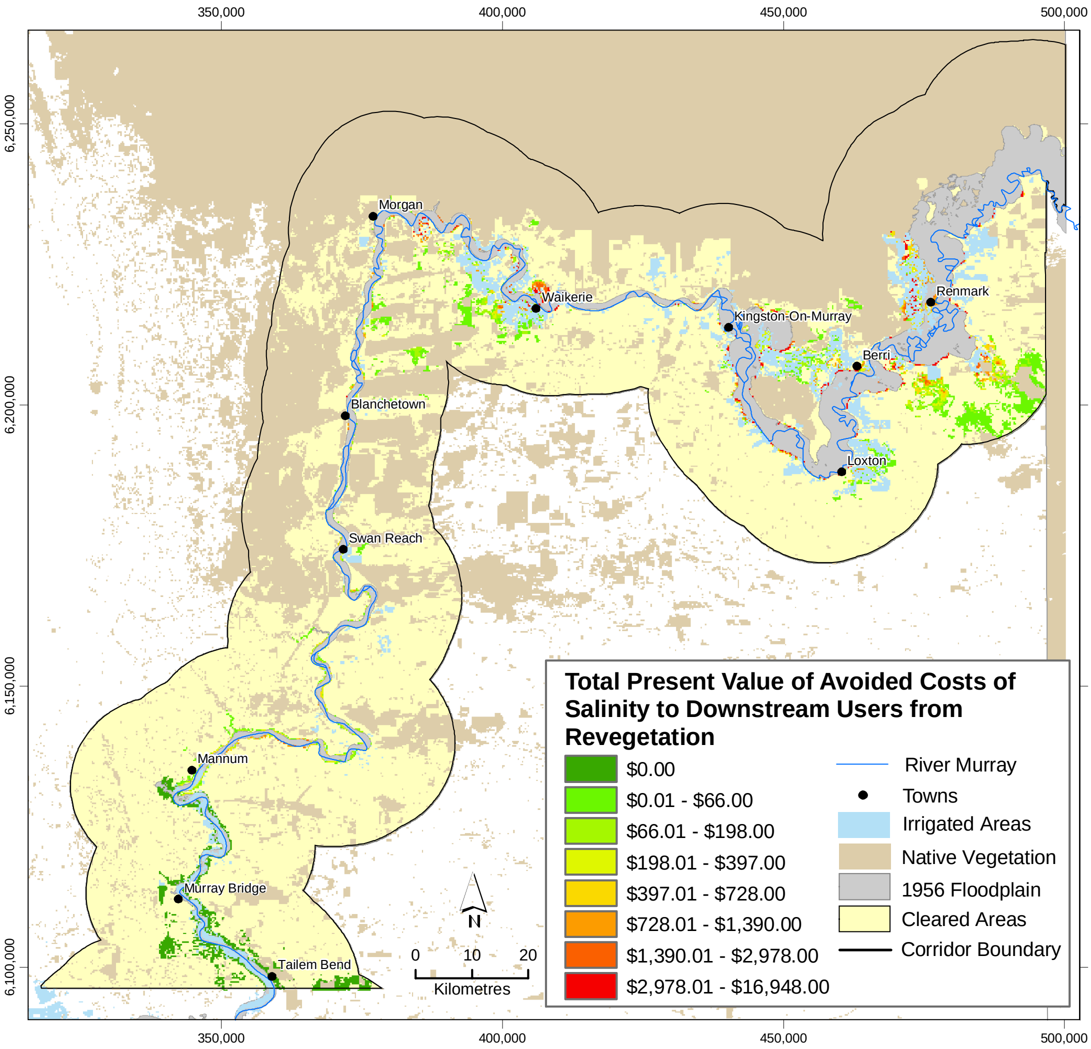

Figure 16 – Total present value of costs of salinity to downstream users avoided by revegetation in present value terms over a timeframe of 100 years.

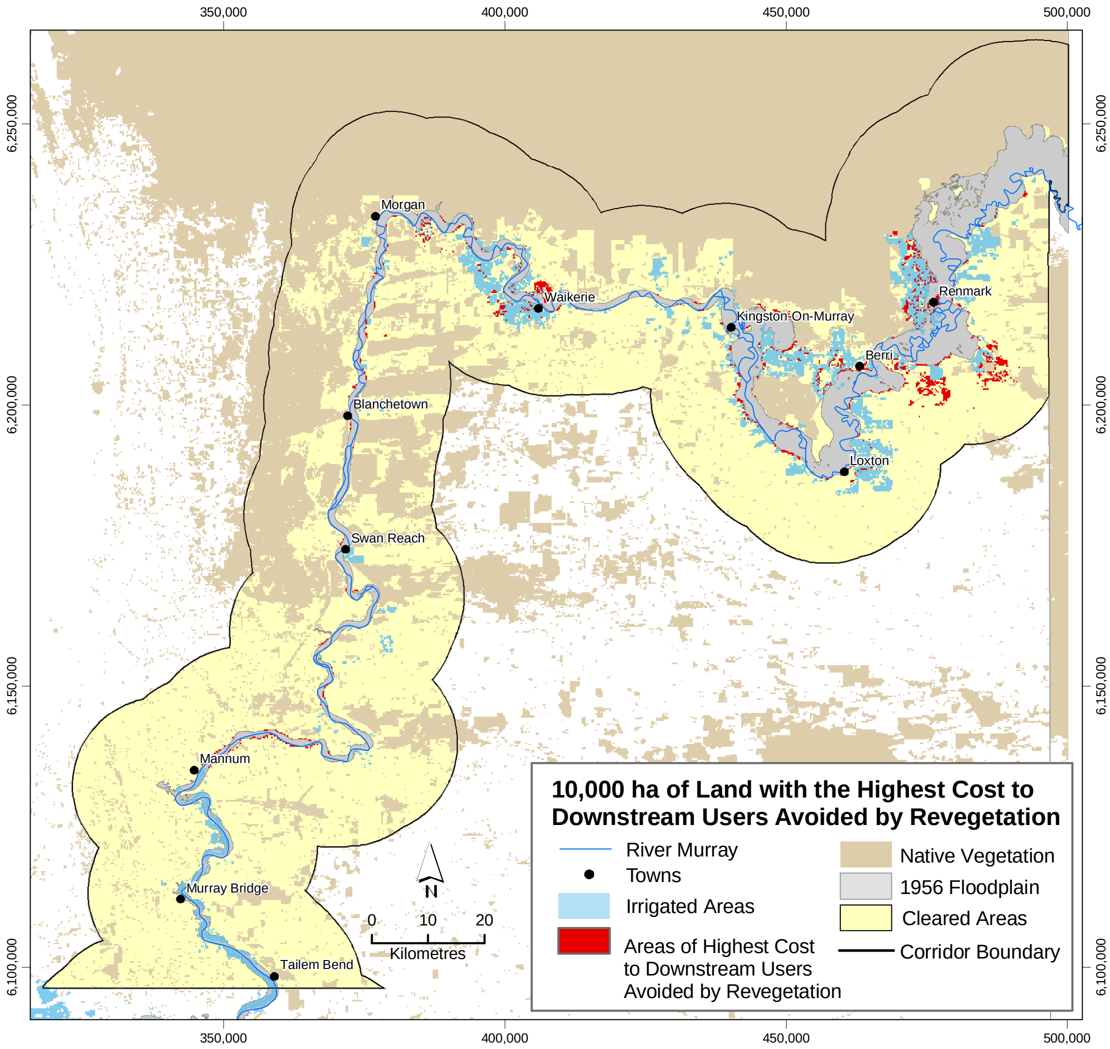

Figure 17 – Spatial distribution of the 10,000 ha of land in the Corridor that has the highest cost to downstream users avoided by revegetation. This layer is used in MCDA.

Barnett and Yan (2004) state that the projected salt contribution to the River Murray from the Riverland is around 30 EC by 2100. However, estimated at just over 4 EC at Morgan, the salinity benefits achieved by revegetation as modelled under the < 100 year time frame represent only a fraction of the total expected salinity contribution of the dryland areas (Barnett and Yan 2004). These estimates from SIMPACT are similar to estimates made in other studies using different methods (Barnett and Yan 2004).

SIMPACT has been effective in identifying the areas providing the highest river salinity benefits from revegetation and these are useful as input into MCDA. However, significant uncertainty surrounds the magnitude of salinity benefits and costs of salinity to downstream users avoided by revegetation. The results of Barnett and Yan (2004) imply that there are substantial salinity benefits to be achieved through recharge reduction associated with revegetation in the dryland areas of the Corridor. The fact that estimates of salinity benefits by SIMPACT fell well short of the potential benefits may result from several sources of error:

- The inability of SIMPACT to model the benefits resulting from areas that are not currently fully wetted up and recharging may result in a considerable underestimation the salinity benefit of revegetation.

- The time taken for revegetation to result in riverine salinity benefits for the River Murray may be longer than the 100 year time frame used in this study resulting in an underestimation the long term salinity benefit of revegetation.
- All SIMPACT models use 1920 as the date of vegetation clearance. However, clearance of remnant vegetation in the region occurred over the period from 1920 to 1970. This will cause salinity benefits to be overestimated and to occur earlier than expected.
- The assumption of SIMPACT that revegetation causes the immediate cessation of recharge may not reflect reality as plants may take some years before they are able to fully intercept rainfall and eliminate recharge. This would also result in an overestimation of salinity benefits of revegetation.

Hence, there is an urgent need for further model calibration and improvement of the SIMPACT algorithms to more accurately represent the processes driving the impact of revegetation on river salinity over time in the Corridor, particularly the wetting and drying scenarios. A better understanding of the salinity benefits of revegetation in the dryland areas of the Corridor to the River Murray may also be gained from taking a longer term modelling approach.

5.1.2 Biodiversity

The conservation of biodiversity is a high priority in regional NRM (Kahrimanis *et al*. 2001) as is reflected by the resource condition targets for vegetation management and revegetation of local native species and native habitat. The resource condition targets specified for terrestrial biodiversity in the Investment Strategy (INRM Group 2000c) specify that 50% of remnant vegetation on private land should be managed and that the area of native vegetation should be increased by 1%. However, NRM actions need to be targeted in high priority areas where the greatest biodiversity benefits can be achieved. Otherwise, conservation efforts will not have optimum benefits for biodiversity. Targeting high priority areas needs planning.

Conservation planning invariably occurs in a highly competitive environment. To ensure the maintenance of biodiversity in a region, nature conservation has to occur within the matrix of competing, productive land uses, and the proportion of the landscape required for biodiversity conservation is not insignificant (Andren, 1994; Freudenberger *et al*., 2004).

Nature conservation generally precludes the undertaking of traditional agricultural land uses including livestock grazing. Non agricultural economic benefits can include more passive uses such as honey production, recreation, carbon sequestration, salinity mitigation and other ecosystem services. However, markets for these more passive economic uses are not nearly as well developed as the existing agricultural land uses and there is limited potential for these in the Corridor. Hence, conservation involves an opportunity cost. Therefore, one of the most important criteria for planning realistic and implementable conservation plans is efficiency (Pressey and Nicholls 1989, Ando *et al*. 1998, Rodrigues *et al*. 2000). The planned system of conservation areas needs to satisfy ecological goals at the minimum cost both in terms of opportunity costs and establishment costs of revegetation.

The resource condition targets specified in the Investment Strategy (INRM Group 2000c) relevant to biodiversity are high level targets and refer only to the total area of vegetation management and revegetation actions required. However, the geographic location of these actions is critically important to their overall benefit to the stated goal of biodiversity conservation. Without smart planning, conservation actions may have very little benefit for biodiversity. The benefit to biodiversity of vegetation management and revegetation actions can be maximised if they occur in high priority locations. General principles are available for the spatially-explicit identification of high priority areas for conservation actions and these are termed *systematic conservation planning* (SCP) principles (Margules and Pressey, 2000). SCP principles can be used to maximise the benefits to biodiversity of expensive conservation actions such as vegetation management and revegetation. This will enhance the existing resource condition targets for the Corridor to the point where vegetation management actions not only address high level resource condition targets but they also have maximum benefit for biodiversity by also meeting ecological goals.

Systematic conservation planning principles (Margules and Pressey 2000) are commonly used to set regional conservation priorities (Kirkpatrick 1983, Margules *et al*. 1988, Bedward *et al*. 1992, Pressey *et al*. 1993, Underhill 1994, Csuti *et al*. 1997, Margules *et al*. 2002, Bryan 2003, Gerner and Bryan 2003a&b). They provide an ideal framework on which to base geographic priority setting for both vegetation management and revegetation for biodiversity. These principles also underpin other regional-scale vegetation protection and management projects (e.g. Moritz and Moss 2003, Oliver 2003, Parkes *et al*. 2003, Dominelli and Smith 2004). These approaches aim to design reserve systems that satisfy established conservation principles most efficiently. SCP principles include comprehensiveness, adequacy, representativeness, efficiency, flexibility, irreplaceability and complementarity. Comprehensiveness refers to the inclusion of the full range of biophysical variation across bioregions. Similarly, representativeness refers to the inclusion of the range of biophysical variation within a bioregion (Austin and Margules 1986). Adequacy is a much more nebulous concept and refers to the ability of a landscape to maintain ecological viability and the integrity of populations, species and communities. Flexibility refers to the design options presented to decision makers as conservation plans need to be flexible to changes dictated by non-biophysical factors. Irreplaceability considers the potential contribution of a site to a reservation goal and the extent to which conservation options are lost if the site is lost (Pressey *et al*. 1994, Ferrier *et al*. 2000). Complementarity involves the selection of sites that are most complementary to existing reserve networks (e.g. Howard *et al*. 1998).

Comprehensiveness operates on an inter-regional scale and is not applicable in this regional scale analysis of the Corridor. For the principle of representativeness (Austin and Margules 1986), vegetation management and revegetation actions should aim to target the range of biophysical diversity as measured by the available data. The concept of representativeness is one of the most widely used systematic conservation planning principles (Margules and Pressey 2000, JANIS 1997). The underlying premise is that if the full diversity of biophysical features is covered then the full range of biodiversity, even the species we have no knowledge of, is also represented by conservation actions. For example, we could set targets of managing 50% of each vegetation community type and each climate type.

Adequacy is a complex concept but should consider all processes affecting the long-term maintenance of biodiversity. It includes the removal of threatening processes, provision for adaptation to climate change and for evolutionary development. With the lack of detailed information on these processes with respect to the biota of the Corridor, adequacy is loosely applied in terms of targeting areas for conservation actions based on the size, shape, fragmentation and connectivity of habitat patches. Targeting locations that have particular landscape structural characteristics may help maintain populations of individual species and/or taxonomic groups because size, shape and juxtaposition of habitat influence the persistence of species (see Fahrig 2003 for a detailed review). Efficient conservation planning minimises the cost of conservation actions whilst still satisfying conservation principles and flexible planning presents options for restoration activities. Complementarity is related to efficiency and is inherently applied in this study as we select the network of sites for conservation actions that together are maximally complementary. The irreplaceability of sites is not considered in this study but may be considered in future analyses.

These conservation planning design concepts provide a useful theoretical basis for setting geographic priorities for both vegetation management and for revegetation of local native species for biodiversity in the Corridor. Systematic conservation planning principles can be directly applied to setting priorities for vegetation management and Bryan (2003) and Crossman and Bryan (in review) have adapted these principles to geographic priority setting for revegetation for biodiversity. However, principles need to be interpreted in the light of the available spatial data and transformed into targets for both vegetation management and revegetation.

Compiling data on the distribution of biodiversity is a precursor to systematic conservation planning (Margules and Pressey, 2000). Comprehensive data of the autecology of all or even some species in a region can rarely be obtained and surrogate data is widely used as a supplement or alternative (e.g. Pressey and Nichols 1989, Bedward *et al*. 1992, Belbin 1993, Wessels *et al*. 1999). The use of biophysical surrogates to characterise the distribution of biodiversity is based on niche theory (Giller 1984). All species are limited in abundance and distribution by a set of environmental variables controlling survival and reproduction (Austin 1985, Austin *et al*. 1990). Thus, theoretically, surrogates that describe the physical environment, and hence, biological potential, are considered to be appropriate measurements of species fundamental niches. The aim in conservation planning should then be to represent homogenous units found within environmental data (i.e. soil land systems), hence maximising the chances of capturing species niches as described by that data. When working with remnant vegetation some biological data can be used such as the distribution of vegetation communities. However, in cleared areas surrogates are often limited to physical environmental variables. Occasionally, records exist of the distribution of pre-disturbance communities, such as in historical databases and 'pre-European' vegetation maps (Bickford and Mackey, 2004). However, these communities may only have been one of many that could have potentially occurred.

Debate surrounds the use of most data types in conservation planning including biophysical surrogates and individual species habitat data as a determinant of biodiversity (e.g. Lambeck 1997, Andelman and Fagan 2000, Lindenmayer *et al.* 2002, Brooks *et al.* 2004, Pressey 2004). It is becoming increasingly evident that we need to include all types of data – biological and physical, modelled and empirical, surrogate and direct (Maddock and du Plessis 1999). In addition, we need to include data on all of the known ecological processes in a region. The most common approach is to include a combination of biological species-based data and biological (e.g. vegetation communities) and physical environmental (e.g. climate) surrogates. This is a conservative approach to conservation planning because the more processes and data types included the greater the chance of capturing the range of biodiversity and enhancing the persistence of biota.

Biodiversity plans are an important first step in planning for the conservation of biodiversity in regions. Biodiversity plans have a valuable role to play in the cataloguing and documenting biodiversity resources and threats to these resources. However they tend not to provide sufficient spatial detail of systematic priorities for efficient conservation based on ecological theory. The role of systematic conservation plans is to take the valuable information assembled in biodiversity plans and apply general SCP principles to guide decision-makers. In this study we use the most relevant and best available data synthesised in the *Biodiversity Plan for the South Australian Murray-Darling Basin* by Kahrimanis *et al*. (2001).

Comprehensive systematic conservation plans have been developed for a only a few well studied regions of the world, most notably western New South Wales, the fynbos global biodiversity hotspot of South Africa (Cowling *et al*. 2003), and the Klamath-Siskiyou Ecoregion in the US (Noss *et al*. 1999). For well-studied data-rich regions comprehensive systematic conservation plans are able to extend the standard SCP principles and select areas that enhance the long term persistence of species. Often, data from metapopulation analyses and autecological studies in these regions can identify key areas for conservation that are essential for maintaining critical ecological processes such as adaptation to climate change through migration along climatic gradients, spatial knowledge of source-sink population dynamics and hotspot areas.

However, in regions that are not yet so well studied we must rely on existing commonly available data on the distribution of vegetation communities, soils, climate and perhaps some rare and threatened species information to set geographic priorities for conservation. The beauty of systematic conservation plans is that they are designed to be iterative and flexible. They can be updated as new information and data becomes available on many factors including species ecology and habitat requirements, migration and dispersal routes and climate change. They can also be updated as conservation actions develop and the priority of different actions changes. In this study we provide a first attempt at identifying geographic priorities for vegetation management and revegetation in the Corridor. The methods used are flexible and can be enhanced with the addition of new information and priorities.

The principles of systematic regional planning for biodiversity as developed in this study are closely aligned with the Naturelinks principles that have been adopted in South Australia (DEH 2003). Specifically, SRP enables the planning of biodiversity conservation activities at a landscape scale and habitat restoration at a large spatial scale. Landscape design principles are incorporated to facilitate the enhanced functioning of metapopulations. An ecological community approach is used in SRP as representative samples of each community type are targeted for conservation and restoration. SRP takes a long term approach to conservation. Finally, SRP includes all available ecological knowledge and provides a flexible framework that enables the inclusion of new concepts and information. Thus, systematic regional planning provides a structured and quantitative approach to implementing the Naturelinks principles for biodiversity conservation and extends these in taking a multiple-objective approach to NRM.

5.1.2.1 Methods and Results

Crossman *et al*. (2004) assembled a variety of existing spatial data layers characterising individual elements of the biodiversity of the SA Murray-Darling Basin to provide input into this study. Extra data layers have been created for setting geographic priorities for both remnant vegetation management and revegetation for biodiversity in this study to supplement those produced by Crossman *et al*. (2004). The data layers were created for the entire SA MDB NRM region and are clipped to the River Murray Corridor. Some rescaling has also been done to prepare the layers for input into the spatial optimisation procedures in MCDA.

The generation of biodiversity layers for input into MCDA are relevant to two NRM actions:

- Remnant vegetation management for biodiversity, and;
- Revegetation of local native species for biodiversity.

Biodiversity layers are included in the MCDA as attributes/criteria and may be used in 2 ways - either as costs in the objective function or as targets in the constraints. The nature of the data layers determines how they are best used in MCDA. Continuous (or *real*) valued data layers are more suited for use in the objective function. In this case the layers are set up as costs with the most desirable aspects of the layer having low values and the least desirable having high values. The objective is then to minimise the cost of the grid cells selected for NRM actions. Categorical data layers such as vegetation communities are best included as constraints. In this case conditional targets are set (e.g. revegetate 15% of each climate zone or revegetate all long term eroding areas). The layers and their usage in MCDA are summarised in Table 3 and described in more detail below and in Crossman *et al*. (2004).

Objective Type	Vegetation Management	Revegetation
Objective Function	Area Shape Fragmentation Habitat Quality	Landscape Context Fragmentation
Constraint	Vegetation Communities (125) Climate Zones (8) Significant Fauna Habitat (11)	Pre-European Vegetation Communities (23) Climate Zones (8) Soil Land Systems (61)

Table 3 – Biodiversity layers generated as attributes and used as either constraints or in the objective function in the MCDA for both vegetation management and revegetation. Attributes used as constraints are followed by the number of classes in brackets. Objective function attributes are continuously scaled between 1 and 4 or 5.

5.1.2.1.1 Vegetation Management Attribute Maps

There are 7 biodiversity attributes relevant to the management of native vegetation (Table 3) with 4 attributes suitable for use in the objective function and three as constraints in MCDA. The Area, Shape, Fragmentation and Habitat Quality attributes derived from DEH regional floristic vegetation datasets are continuously valued cost scores suitable for use in the objective function. Each attribute has either integer or real cost scores ranging between 1 and 4 or 5 to enable numerically unbiased combination of criteria. Cost scores are ranked based on conservation priority with highest priority given the lowest cost score of 1 and lowest priority given the highest cost score of 5. The objective is to minimise the total cost scores.

Area

A generally accepted conservation principle is that bigger patches are better for biodiversity conservation (e.g. Diamond 1975, Diamond and May 1976, Gilpin and Soule 1986, Saunders *et al.* 1991, Hanski 1994, Fahrig 2003). In general, larger areas can support larger populations and are generally able to support more species. We calculate the area of each patch of remnant vegetation, categorise into five classes, and prioritise according to this principle (Table 4; Figure 18).

Area Categories	Cost Score	Area (ha)	Number of Patches
>= 500 ha	1	449,173	161
200 ha – 499 ha	2	17,781	123
100 ha – 199 ha	3	12,310	141
50 ha – 99 ha	4	8,877	178
< 50 ha	5	22,735	1602

Table 4 – Area classification and prioritisation of remnant vegetation patches.

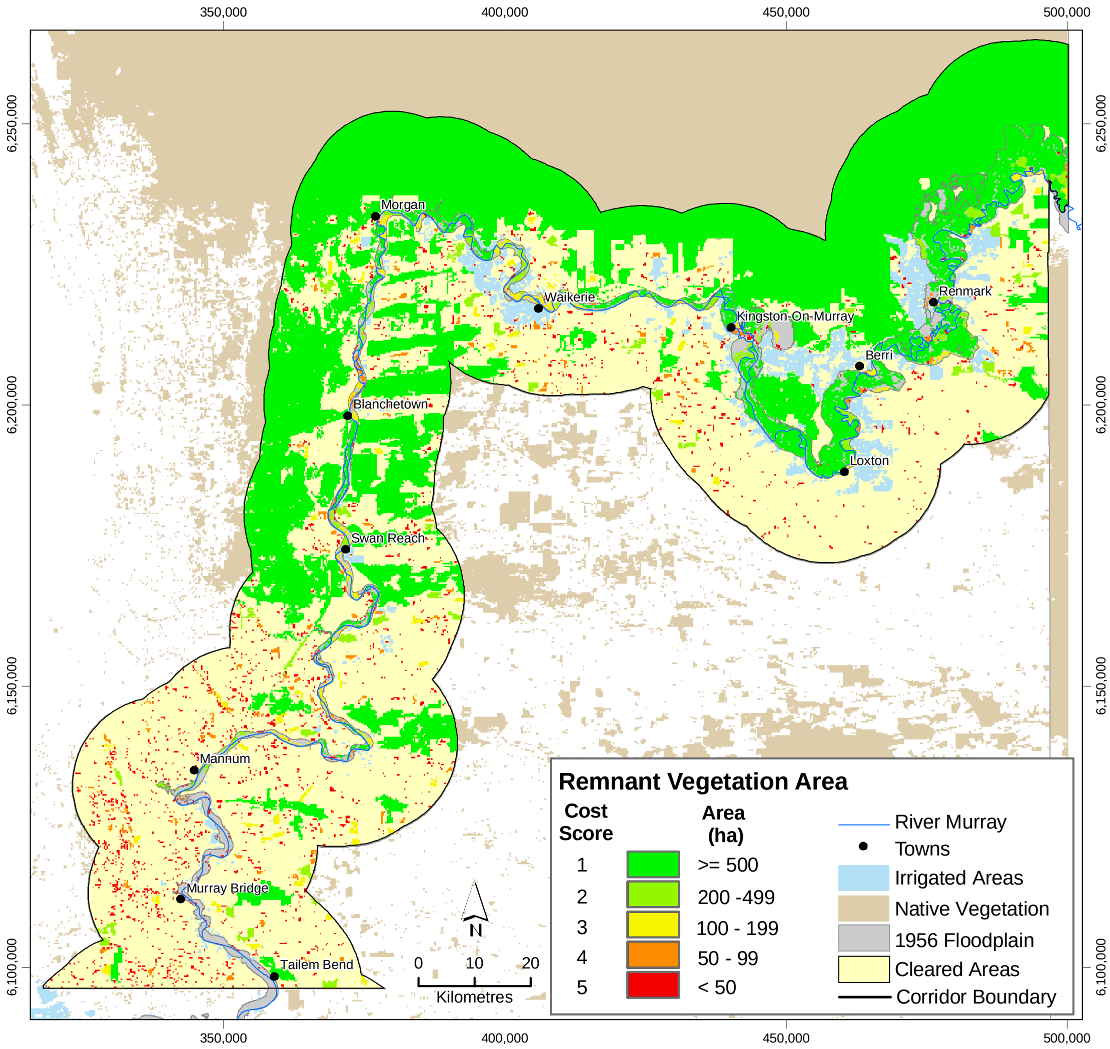

Figure 18 – Area of remnant vegetation patches in the study area classified into 5 classes with largest patches having the lowest cost score (1) and smallest patches having the highest cost score (5). Hence, in MCDA the algorithm will prefer larger patches over smaller for vegetation management as it tries to minimise costs.

Shape

Another well-established conservation principle is that patches with simpler shapes are better for biodiversity conservation than patches with more complex shapes (Diamond 1975, Diamond and May 1976, Saunders *et al.* 1991, Fahrig 2003). Linear strips and small patches with complex edges will be more susceptible to deleterious edge effects such as weed invasion, wind and other microclimatic changes, changed nutrient and water regimes and increased predation levels. Crossman *et al*. (2004) calculates the shape index of each patch of remnant vegetation as the patch perimeter divided by the square root of the patch area and adjusted for circular standard. Shape index is then categorised into five classes, and given a cost score according to the complexity of the patch shape index. Patches with simple shape have a low cost score and patches with a complex shape have a high cost score (Table 5; Figure 19).

Shape Categories	Cost Score	Area (ha)	Number of Patches
1 – 1.499	1	17,103	940
1.5 – 1.999	2	19,987	527
2 – 2.999	3	33,852	388
3 – 4.999	4	35,406	204
>= 5	5	404,528	241

Table 5 – Shape classification and prioritisation of remnant vegetation patches.

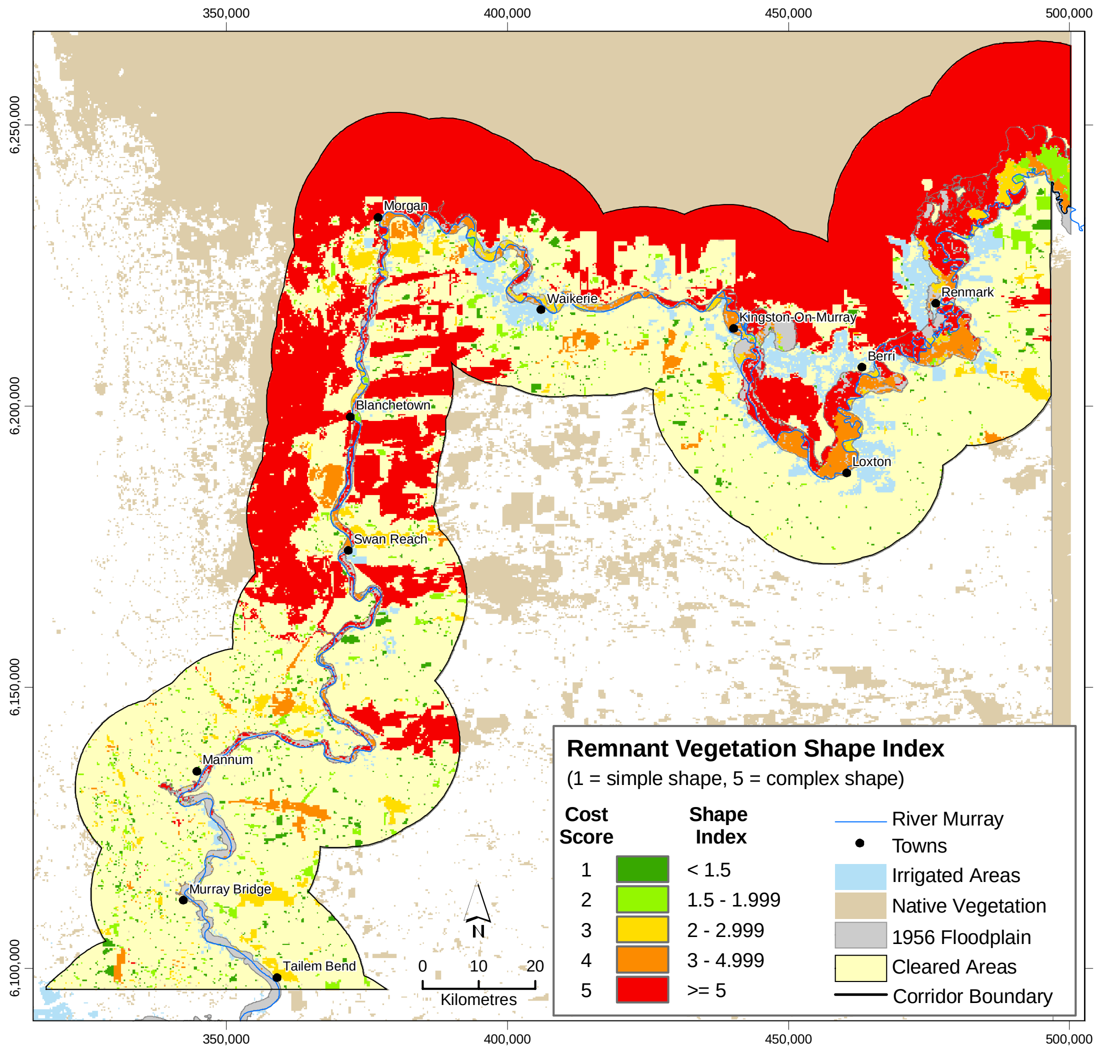

Figure 19 – Shape index of remnant vegetation patches in the study area classified into 5 cost scores with patches of simplest shape having the lowest cost scores (1) and patches of most complex shape having the highest cost scores (5). Hence, in MCDA the algorithm will prefer more simply shaped patches over more complex shapes for vegetation management.

Fragmentation

Recent attention has focussed on landscape planning and the conceptualisation of human-modified landscapes (McIntyre and Hobbs 1999, 2000, Fischer *et al.* 2004). McIntyre and Hobbs (1999) suggest a set of four states of landscape fragmentation – intact, variegated, fragmented, and relictual. These states are defined according to the percentage of native vegetation remaining in the landscape. The distribution of these landscape states is mapped by calculating for each grid cell the percentage vegetation cover within a 5km neighbourhood. Cost score are attributed to grid cells according to the management recommendations of McIntyre and Hobbs (2000) (Table 6, Figure 20).

Fragmentation Categories	% Vegetation Remaining in Neighbourhood	Cost Score	Area (ha)
Intact	90% +	1	184,406
Variegated	60 – 89.9%	2	140,902
Fragmented	10 – 59.9%	3	174,277
Relictual	< 10%	4	11,290

Table 6 – Landscape context classification based on the McIntyre and Hobbs (2000) schema.

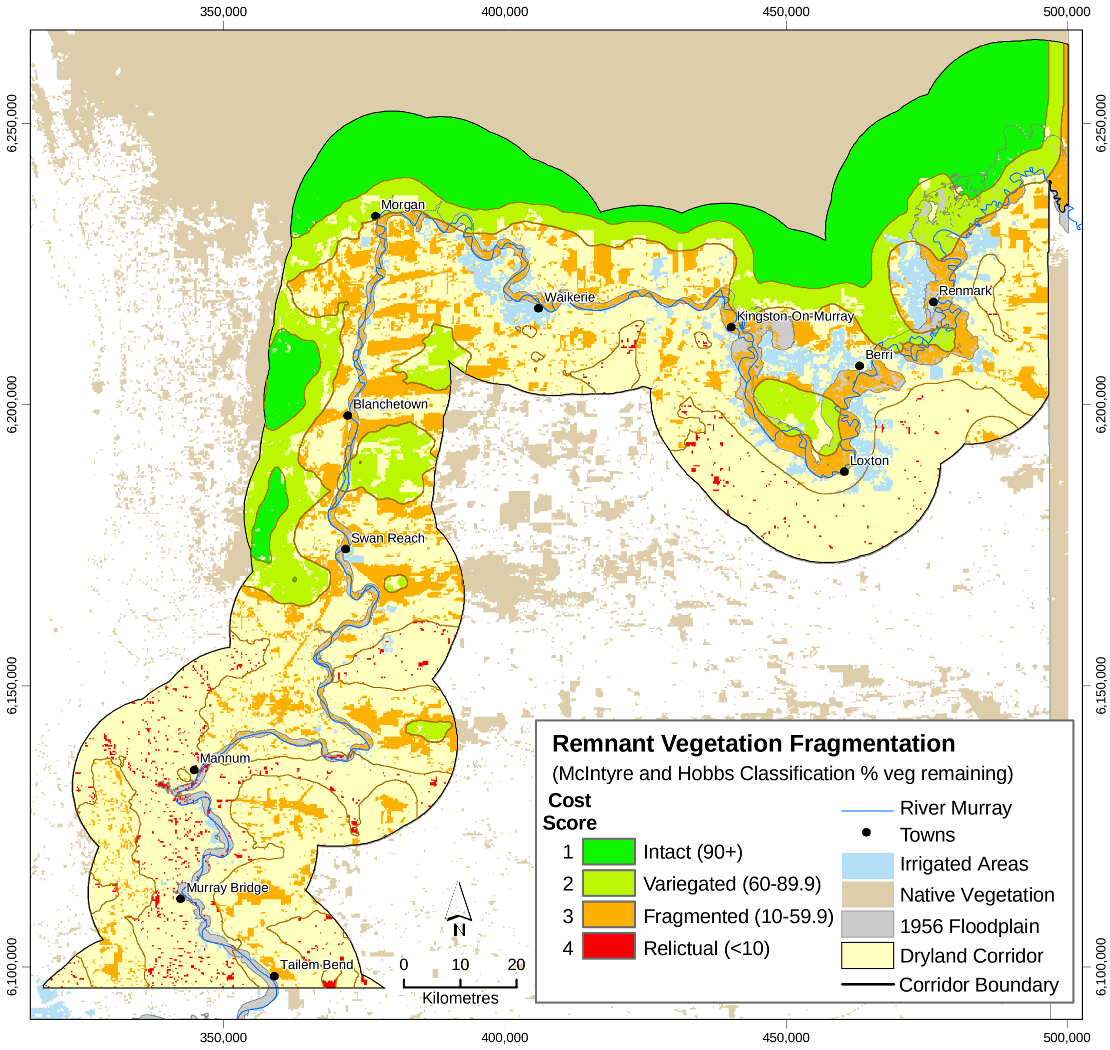

Figure 20 – Fragmentation of remnant vegetation grid cells in the study area classified into 4 classes with cells whose neighbourhood is intact (>90% of land in 5km radius is vegetated) having the lowest cost score (1) and cells whose neighbourhood is relictual (<10% of land in 5km radius is vegetated) having the highest cost score (4). Hence, in MCDA the algorithm will prefer intact cells for vegetation management.

Habitat Quality

This attribute is based on the premise that areas in the interior of patches are the highest quality habitat areas within a patch. This is generally the case because of the reduction in edge effects experienced in the interior of patches compared to the edge of patches. Hence, the threats to biodiversity are reduced and any vegetation management actions have a better chance at success because of the fewer threats affecting ecological processes. Inclusion of this attribute as a cost also encourages the spatial clumping of high priority grid cells and the identification of core areas for vegetation management. Calculation of this attribute layer involved using a distance function in GIS to calculate the shortest distance from each vegetated grid cell to the nearest cleared grid cell. These distance values were then linearly rescaled to continuous values between 1 and 5 (Figure 21).

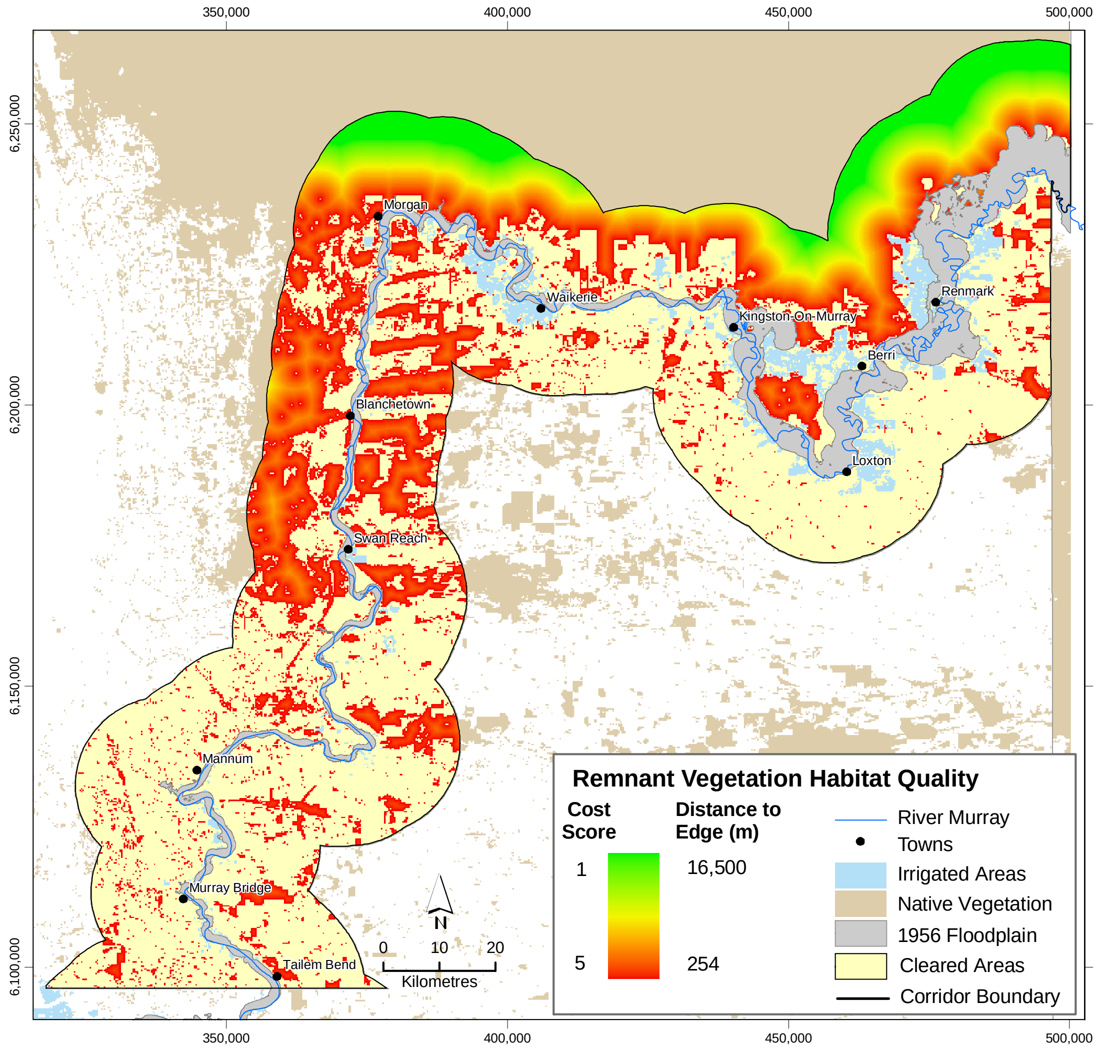

Figure 21 – Habitat quality of remnant vegetation patches in the study area. This attribute is the distance of each vegetated grid cell to the nearest patch edge linearly rescaled to continuous values between 1 and 5 with vegetated cells furthest from the patch edge having the lowest cost score (1) and cells closest to the patch edge having the highest cost score (5). Hence, in MCDA the algorithm will prefer cells further from the patch edge over those closer to the edge for vegetation management.

The three attributes of Vegetation Communities, Climate Zones and Rare and Threatened Species Habitat are categorical attributes suitable for use as constraints in MCDA. Each attribute layer consists of categorical data and the four have different numbers of classes (Table 3). To use as constraints we create a binary grid for each class of each attribute layer where grid cells are given a value of 1 or 0 depending on whether the grid cell supports the class or not. In the maps below however, the classes are presented as categories on a single map for each attribute where possible. The principle of representativeness is implemented using the constraint layers. Each layer characterises the spatial distribution of some element of biophysical diversity and constraints are set such that a certain proportion of each biophysical class is represented by the conservation action of vegetation management.

Remnant Vegetation Communities

Vegetation management actions should cover the range of remnant vegetation communities. Theoretically, the full diversity of habitats and component plant and animal species will then benefit from vegetation management actions in the Corridor. Vegetation communities have been mapped by DEH using a combination of field survey and aerial photography interpretation. A total of 131 vegetation communities are identified by DEH in the Corridor. The vegetation mapping has a high spatial resolution which needed to be rasterised into 254 m grid cells for inclusion in the MCDA. Some detail is necessarily generalised in this process. In particular, some communities are very small in area and 6 communities disappeared altogether when rasterised into grid format. Thus, a total of 125 vegetation communities are used in MCDA (Table 7).

Code	Description	Structure	Area (ha)
1	Acacia brachybotrya, Beyeria lechenaultii	Shrubland	428
2	Acacia nyssophylla over Enchylaena tomentosa var. tomentose	Tall Very Open Shrubland	2,400
3	Acacia nyssophylla, +/- Myoporum montanum over +/- Maireana sedifolia	Shrubland	586
4	Acacia stenophylla over Chenopodium nitrariaceum	Low Woodland	16
5	Acacia stenophylla over Enchylaena tomentosa var. tomentosa	Low Woodland	76
6	Acacia stenophylla over Muehlenbeckia florulenta Enchylaena tomentosa var. tomentosa	Low Woodland	266
7	Agrostis avenacea var. avenacea over Eleocharis acuta +/- Polypogon monspeliensis	Tussock Grassland	258
8	Allocasuarina verticillata over +/- Xanthorrhoea semiplana ssp., Themeda triandra, Gonocarpus elatus, Lomandra multiflora ssp. dura, Stipa blackii	Low Woodland	156
9	Allocasuarina verticillata, +/- Callitris preissii over Lomandra effusa, Stipa sp., Danthonia sp.	Low Woodland	345
10	Angianthus tomentosa over Atriplex lindleyi ssp. lindleyi Herbland	Herbland	336
11	Atriplex lindleyi ssp. lindleyi +/- Sclerolaena muricata var. muricata over +/- Atriplex semibaccata	Low Shrubland	3,849
12	Atriplex rhagodioides	Shrubland	58
13	Atriplex rhagodioides over Enchylaena tomentosa var. tomentosa +/- Halosarcia pergranulata ssp. pergranulata +/- Disphyma crassifolium ssp. clavellatum	Shrubland	2,160
14	Atriplex stipitata, +/- Maireana tricoptera, +/- M. pentatropis, +/- Zygophyllum sp.	Low Open Shrubland	3,405
15	Atriplex vesicaria +/- Maireana sedifolia	Low Open Shrubland	391
16	Atriplex vesicaria, Maireana astrotricha, +/- Maireana pyramidata, +/- Sclerolaena obliquicuspis, +/- Maireana sedifolia	Low Open Shrubland	1,891
17	Banksia ornata commonly associated with Allocasuarina pusilla, Leptospermum coriaceum over Hibbertia riparia, Lepidosperma congestum/laterale/viscidum	Tall Open Shrubland	319
18	Callitris preissii over Stipa sp., Enchylaena tomentosa var. tomentosa	Low Open Woodland	776
19	Callitris preissii over Stipa sp., Enchylaena tomentosa var. tomentosa, Einadia nutans ssp., Danthonia sp., Senecio lautus	Low Woodland	318
20	Casuarina pauper +/- Alectryon oleifolius ssp. canescens over Rhagodia spinescens, Maireana pentagona, Maireana sedifolia, Enchylaena tomentosa var., Atriplex vesicaria ssp., A. stipitata,	Low Open Woodland	1,059
21	Casuarina pauper over Enchylaena tomentosa var. tomentosa, Sclerolaena diacantha, Maireana sedifolia, Senna artemisioides ssp.	Very Low Open Woodland	1,973
22	Casuarina pauper over Stipa sp., Sclerolaena diacantha/uniflora, Enchylaena tomentosa var. tomentosa, Senna artemisioides ssp.	Low Woodland	1,287
23	Casuarina pauper, +/- Alectryon oleifolius, +/- Myoporum platycarpum over chenopods, Senna artemisioides ssp., Olearia spp., Eremophila spp., Dodonaea spp., Acacia aneura	Low Woodland	364
24	Chenopodium nitrariaceum	Shrubland	271
25	Danthonia spp., Stipa spp., +/- Enneapogon intermedius, +/- Enneapogon avenaceus, +/- introduced spp., +/- Sclerolaena spp., +/- Maireana trichoptera, +/- Eriochiton sclerolaenoides, +/- Atriplex spp., +/- Myoporum platycarpum, +/- Alectryon oleifolius	Open (Tussock) Grassland	4,791
26	Disphyma crassifolium ssp. clavellatum over Atriplex lindleyi ssp. Lindleyi	Very Open Mat Plants	2,137
27	Dodonaea viscosa ssp. Angustissima	Low Shrubland	486
28	Dodonaea viscosa ssp. angustissima over *Bromus rubens *Schismus barbatus +/- Enchylaena tomentosa var. tomentosa	Open Shrubland	113
29	Dodonaea viscosa ssp. angustissima, Senna artemisioides ssp., Eremophila sturtii, Acacia burkittii, Acacia colletioides, Acacia nyssophylla, Acacia victoriae ssp. victoriae over Enchylaena tomentosa, Scleroleana spp.	Open Shrubland	6,217
30	Enchylaena tomentosa var. tomentosa over Stipa sp., Danthonia sp.	Low Open Shrubland	261
31	Enchylaena tomentosa var., Maireana brevifolia, +/- Atriplex semibaccata over Maireana erioclada, Euphorbia terracina	Low Shrubland	1
32	Eragrostis australasica Muehlenbeckia florulenta over Trichanthodium skirrophorum Senecio glossanthus	Open Tussock Grassland	751
33	Eucalyptus 'anceps', +/- E. leptophylla over Rhagodia crassifolia, Enchylaena tomentosa var. tomentosa, Stipa scabra group, Triodia irritans Vittadinia cuneata var. cuneata forma cuneata	Mallee	2,388
34	Eucalyptus baxteri, +/- E. leucoxylon ssp., +/- Allocasuarina verticillata over Xanthorrhoea semiplana ssp. semiplana, Acacia pycnantha, Astroloma conostephioides, Geranium retrorsum, Pimelea humilis	Low Woodland	121
35	Eucalyptus brachycalyx, E. rugosa	Mallee	39
36	Eucalyptus calycogona var. calycogona, E. dumosa over Stipa sp., Danthonia sp.	Open Mallee	95
37	Eucalyptus calycogona, E. dumosa over Stipa sp., Danthonia sp.	Very Open Mallee	7
38	Eucalyptus camaldulensis var. camaldulensis	Woodland	349
39	Eucalyptus camaldulensis var. camaldulensis +/- E. largiflorens over Chenopodium nitrariaceum +/- Acacia stenophylla +/- Muehlenbeckia florulenta	Open Forest	224
40	Eucalyptus camaldulensis var. camaldulensis E. largiflorens over Acacia stenophylla	Open Forest	354
41	Eucalyptus camaldulensis var. camaldulensis E. largiflorens over Senecio cunninghamii var. cunninghamii +/- Phragmites australis	Open Forest	306
42	Eucalyptus camaldulensis var. camaldulensis E. largiflorens over +/- Enchylaena tomentosa var. tomentosa +/- Muehlenbeckia florulenta +/- Cyperus gymnocaulos	Woodland	1,609
43	Eucalyptus camaldulensis var. camaldulensis E. largiflorens over Muehlenbeckia florulenta +/- Acacia stenophylla	Woodland	7,882
44	Eucalyptus camaldulensis var. camaldulensis over +/- Acacia stenophylla +/- Cyperus gymnocaulos +/- Paspalidium jubiflorum	Open Forest	471
45	Eucalyptus camaldulensis var. camaldulensis over +/- Cyperus gymnocaulos +/- Senecio cunninghamii var. cunninghamii	Woodland	1,594
46	Eucalyptus camaldulensis var. camaldulensis over Acacia pycnantha, A. retinodes var. retinodes, Callistemon sieberi, Cyperus vaginatus, *Briza maxima, *Senecio pterophorus var. pterophorus, Themeda triandra	Woodland	1
47	Eucalyptus camaldulensis var. camaldulensis over Muehlenbeckia florulenta +/- Cyperus gymnocaulos	Open Forest	1,164
48	Eucalyptus camaldulensis var. camaldulensis over Muehlenbeckia florulenta +/- Paspalidium jubiflorum +/- Cyperus gymnocaulos +/- Acacia stenophylla	Woodland	3,027
49	Eucalyptus camaldulensis var. camaldulensis over Phragmites australis and Muehlenbeckia florulenta	Open Forest	1,556
50	Eucalyptus camaldulensis var. camaldulensis over Phragmites australis +/- Muehlenbeckia florulenta	Woodland	1,253
51	Eucalyptus camaldulensis var. camaldulensis, Acacia stenophylla over Muehlenbeckia florulenta Paspalidium jubiflorum	Woodland	260
52	Eucalyptus cyanophylla, +/- E. socialis over Sclerolaena diacantha/uniflora, Triodia irritans var.	Open Mallee	6,191
53	Eucalyptus dumosa, +/- E. gracilis over Melaleuca acuminata, Atriplex stipitata, Zygophyllum apiculatum,Stipa mollis group, Senecio lautus	Open Mallee	1,135
54	Eucalyptus dumosa, +/- E. leptophylla over Stipa sp., Danthonia sp., Lepidosperma congestum/laterale/viscidum	Mallee	273
55	Eucalyptus dumosa, Eucalyptus socialis, +/- Eucalyptus leptophylla, +/- Eucalyptus incrassata over Triodia irritans, Beyeria opaca, Eremophila glabra	Open Mallee	9,540
56	Eucalyptus fasciculosa, over +/- Lomandra effusa, Stipa sp., Danthonia sp.	Open Woodland	480
57	Eucalyptus gracilis, +/- E. oleosa over Sclerolaena diacantha/uniflora, Stipa sp., Zygophyllum apiculatum, Maireana pentatropis	Open Mallee	43,516
58	Eucalyptus gracilis, E. oleosa over Maireana sedifolia, Atriplex sp.	Open Mallee	5,383
59	Eucalyptus gracilis, E. oleosa over Sclerolaena diacantha/uniflora, Stipa sp., Maireana pentatropis, Zygophyllum apiculatum	Very Open Mallee	39,078
60	Eucalyptus gracilis, Eucalyptus oleosa, +/- Eucalyptus socialis over Zygophyllum aurantiacum, Enchylaena tomentosa var. tomentosa, Grevillea huegelii, Olearia muelleri, Senna artemisioides sspp. and chenopod shrubs	Open Mallee	104,219
61	Eucalyptus incrassata +/- E. leptophylla over Leptospermum coriaceum, Melaleuca uncinata, Callitris verrucosa, Baeckea behrii, Hibbertia riparia, Glischrocaryon behrii	Open Mallee	3,514
62	Eucalyptus incrassata, Leptospermum coriaceum over Hibbertia riparia, Baeckea behrii, Callitris verrucosa, Glischrocaryon behrii, Melaleuca uncinata	Open Low Mallee	3,680
63	Eucalyptus largiflorens Acacia stenophylla over Muehlenbeckia florulenta Enchylaena tomentosa var. tomentosa	Low Open Forest	1,223
64	Eucalyptus largiflorens E. camaldulensis var. camaldulensis over Callistomen brachyandrus and Enchylaena tomentosa var. tomentosa	Open Forest	311
65	Eucalyptus largiflorens +/- E. camaldulensis var. camaldulensis over Halosarcia pergranulata ssp. pergranulata +/- H. indica ssp. leiostachya +/- Disphyma crassifolium ssp. clavellatum	Woodland	535
66	Eucalyptus largiflorens over +/- Atriplex rhagodioides +/- Enchylaena tomentosa var. tomentosa +/- Disphyma crassifolium ssp. Clavellatum	Low Woodland	7,704
67	Eucalyptus largiflorens over +/- Muehlenbeckia florulenta	Open Woodland	82
68	Eucalyptus largiflorens over Chenopodium nitrariaceum +/- Muehlenbeckia florulenta +/- Eremophila divaricata	Low Open Forest	1,631

69	Eucalyptus largiflorens over Enchylaena tomentosa var. tomentosa +/- Paspalidium jubiflorum	Low Open Forest	557
70	Eucalyptus largiflorens over Maireana pyramidata	Low Woodland	120
71	Eucalyptus largiflorens over Muehlenbeckia florulenta	Open Woodland	2,840
72	Eucalyptus largiflorens over Muehlenbeckia florulenta +/- Enchylaena tomentosa var. tomentosa	Open Forest	982
73	Eucalyptus largiflorens over over Stipa sp., Einadia nutans ssp., Enchylaena tomentosa var.	Low Woodland	18
74	Eucalyptus leptophylla, E. socialis over Triodia irritans var., Stipa sp.	Open Mallee	5,702
75	Eucalyptus leucoxylon ssp. over +/- Lomandra effusa	Open Woodland	51
76	Eucalyptus leucoxylon ssp., +/- E. viminalis ssp. over Acacia pycnantha, Scaevola albida	Woodland	18
77	Eucalyptus odorata over Acacia acinacea, Chenopodium desertorum ssp. desertorum, Dianella revoluta var. revoluta, Lomandra densiflora, Eutaxia microphylla var. microphylla	Low Woodland	23
78	Eucalyptus porosa Acacia stenophylla over Muehlenbeckia florulenta	Low Open Woodland	1
79	Eucalyptus porosa over Stipa sp., Lomandra effusa, Helichrysum leucopsideum, Senecio lautus, Clematis microphylla, Danthonia sp.	Low Open Woodland	1,770
80	Eucalyptus porosa over Stipa sp., Lomandra effusa, Helichrysum leucopsideum, Senecio lautus	Low Woodland	1,782
81	Eucalyptus socialis, +/- Eucalyptus oleosa, +/- Eucalyptus dumosa over Enchylaena tomentosa var. tomentosa, Zygophyllum spp., Olearia muelleri, Westringia rigida, Triodia irritans	Open Mallee	56,264
82	Gahnia filum +/- Gahnia trifida +/- Juncus kraussii over Suaeda australis + - Samolus repens	Sedgeland	1
83	Geijera linearifolia, Myoporum platycarpum ssp., +/- Alectryon oleifolius ssp. canescens over Acacia nyssophylla, Senna artemisioides nothossp. coriacea, Zygophyllum aurantiacum ssp., Eriochiton sclerolaenoides, Sclerolaena obliquicuspis	Low Open Woodland	23,221
84	Halosarcia indica ssp. leiostachya over +/- Suaeda australis +/- Disphyma crassifolium ssp. Clavellatum	Low Shrubland	492
85	Halosarcia pergranulata ssp. pergranulata +/- Halosarcia indica ssp. leiostachya over +/- Disphyma crassifolium ssp. Clavellatum	Low Shrubland	3,347
86	Halosarcia pergranulata ssp. pergranulata over +/- *Critesion marinum +/- Disphyma crassifolium ssp. clavellatum +/- Suaeda australis	Low Shrubland	3,917
87	Halosarcia sp. over Disphyma crassifolium ssp. Clavellatum	Low Very Open Shrubland	823
88	Halosarcia sp., Sclerostegia sp.	Low Open Shrubland	117
89	Juncus kraussii over +/- Suaeda australis +/- Samolus repens	Sedgeland	2
90	Lomandra effusa with Lepidosperma congestum/laterale/viscidum, Asphodelus fistulosus, Cryptandra amara var.	Open Sedgeland	704
91	Lomandra effusa, +/- Helichrysum leucopsideum	Open Tussock Grassland	201
92	Maireana aphylla over Lomandra multiflora ssp. dura, L. effusa, Danthonia caespitosa, Vittadinia sp.	Low Shrubland	56
93	Maireana brevifolia over Enchylaena tomentosa var. tomentosa	Low Open Shrubland	438
94	Maireana pyramidata over +/- Atriplex lindleyi ssp. lindleyi +/- *Schismus barbatus	Low Open Shrubland	1,362
95	Maireana pyramidata over Stipa sp., Enchylaena tomentosa var. tomentosa, Rhagodia spinescens	Very Open Shrubland	467
96	Maireana pyramidata, +/- Atriplex vesicaria ssp., +/- Maireana georgei, +/- Maireana turbinata, +/- Maireana sedifolia, +/- Enchylaena tomentosa var. tomentosa, +/- Sclerolaena obliquicuspis	Low Open Shrubland	7,107
97	Maireana sedifolia over Enchylaena tomentosa var. tomentosa, Eriochiton sclerolaenoides, Rhagodia spinescens, Sclerolaena obliquicuspis	Very Open Shrubland	9,556
98	Maireana sedifolia, +/- *Lycium australe over Sclerolaena obliquicuspis, Rhagodia spinescens, Rhagodia ulicina	Shrubland	7,964
99	Maireana sedifolia, +/- Sclerolaena obliquicuspis, +/- Eriochiton sclerolaenoides, +/- Enchylaena tomentosa var. tomentosa, +/- Carrichtera annua	Low Open Shrubland	28,059
100	Melaleuca acuminata, M. lanceolata +/- Eucalyptus socialis, +/- E. leptophylla over Stipa sp., Danthonia sp.	Tall Open Shrubland	3,022
101	Melaleuca halmaturorum ssp. halmaturorum	Tall Open Shrubland	20
102	Melaleuca halmaturorum ssp. halmaturorum over +/- Juncus kraussii +/- Samolus repens +/- Suaeda australis +/- Sarcocornia quinqueflora	Very Low Open Forest	5
103	Melaleuca lanceolata ssp. lanceolata +/- Eucalyptus largiflorens over +/- Enchylaena tomentosa var. tomentosa	Low Open Forest	1,367
104	Melaleuca lanceolata ssp. lanceolata +/- Melaleuca acuminata over Dodonaea hexandra, Gahnia deusta, Lepidosperma viscidum	Shrubland	1,051
105	Melaleuca lanceolata ssp. lanceolata over Beyeria lechenaultii	Shrubland	139
106	Melaleuca lanceolata ssp. lanceolata, +/- Callitris preissii over Enchylaena tomentosa var., Atriplex sp., Stipa sp.	Tall Open Shrubland	96
107	Melaleuca uncinata	Closed Shrubland	58
108	Muehlenbeckia florulenta	Shrubland	170
109	Muehlenbeckia florulenta over +/- Enchylaena tomentosa var. tomentosa +/- Halosarcia pergranulata ssp. pergranulata +/- Suaeda australis	Tall Shrubland	7,863
110	Muehlenbeckia florulenta over +/- Sporobolus mitchellii +/- Sporobolus virginicus	Shrubland	3,979
111	Myoporum platycarpum	Low Woodland	1,362
112	Nitraria billardierei over Salsola kali	Low Open Shrubland	35
113	Nitraria billardierei, Lycium australe, Sclerostegia tenuis, Disphyma crassifolium ssp. clavellatum, +/- Maireana aphylla, +/- Sclerolaena brachyptera, +/- Maireana pyramidata, +/- Eragrostis australasica, +/- Muehlenbeckia florulenta	Low Open Shrubland	2,065
114	Pachycornia triandra over +/- Disphyma crassifolium ssp. clavellatum	Low Open Shrubland	1,016
115	Phragmites australis +/- Typha domingensis +/- Schoenoplectus validus over +/- *Paspalum vaginatum +/- *Paspalum distichum	Closed (Tussock) Grassland	794
116	Phragmites australis over +/- Muehlenbeckia florulenta +/- Bolboschoenus caldwellii	Closed (Tussock) Grassland	356
117	Phragmites australis, +/- Juncus sp., +/- Typha sp.	Sedgeland	196
118	Polycalymma stuartii +/- Enchylaena tomentosa var. tomentosa	Herbland	94
119	Sarcocornia quinqueflora over +/- Samolus repens +/- Suaeda australis	Low Shrubland	24
120	Sclerolaena tricuspis Sclerolaena brachyptera over +/- Brachycome lineariloba +/- Plantago cunninghamii	Low Open Shrubland	1,576
121	Sclerostegia arbuscula over +/- Sarcocornia quinqueflora +/- *Critesion marinum +/- Suaeda australis	Low Shrubland	198
122	Senna artemisioides, +/- Acacia calamifolia, +/- Eremophila longifolia	Shrubland	279
123	Sporobolus virginicus or Sporobolus mitchellii over +/- Sclerolaena tricuspis	Tussock Grassland	1,497
124	Stipa sp. with sparse low shrubs occasionally present including Sclerolaena diacantha/uniflora	Open Tussock Grassland	35,652
125	Stipa sp., +/- Sclerolaena diacantha/uniflora, Danthonia sp., Hyalosperma semisterile	Open Tussock Grassland	1,951
126	Suaeda australis +/- Sarcocornia quinqueflora over +/- Samolus repens	Low Closed Shrubland	85
127	Triodia irritans	Hummock Grassland	213
128	Typha domingensis over +/- *Paspalum vaginatum +/- *Paspalum distichum	Sedgeland	100
129	Typha domingensis, over Schoenoplectus validus, Aster subulatus Paspalum distichum, Hydrocotyle verticillata	Sedgeland	76
130	Typha orientalis over +/- Schoenoplectus validus	Sedgeland	69
131	Willows	Introduced	95

Table 7 – Vegetation communities in the Corridor as classified and mapped by DEH.

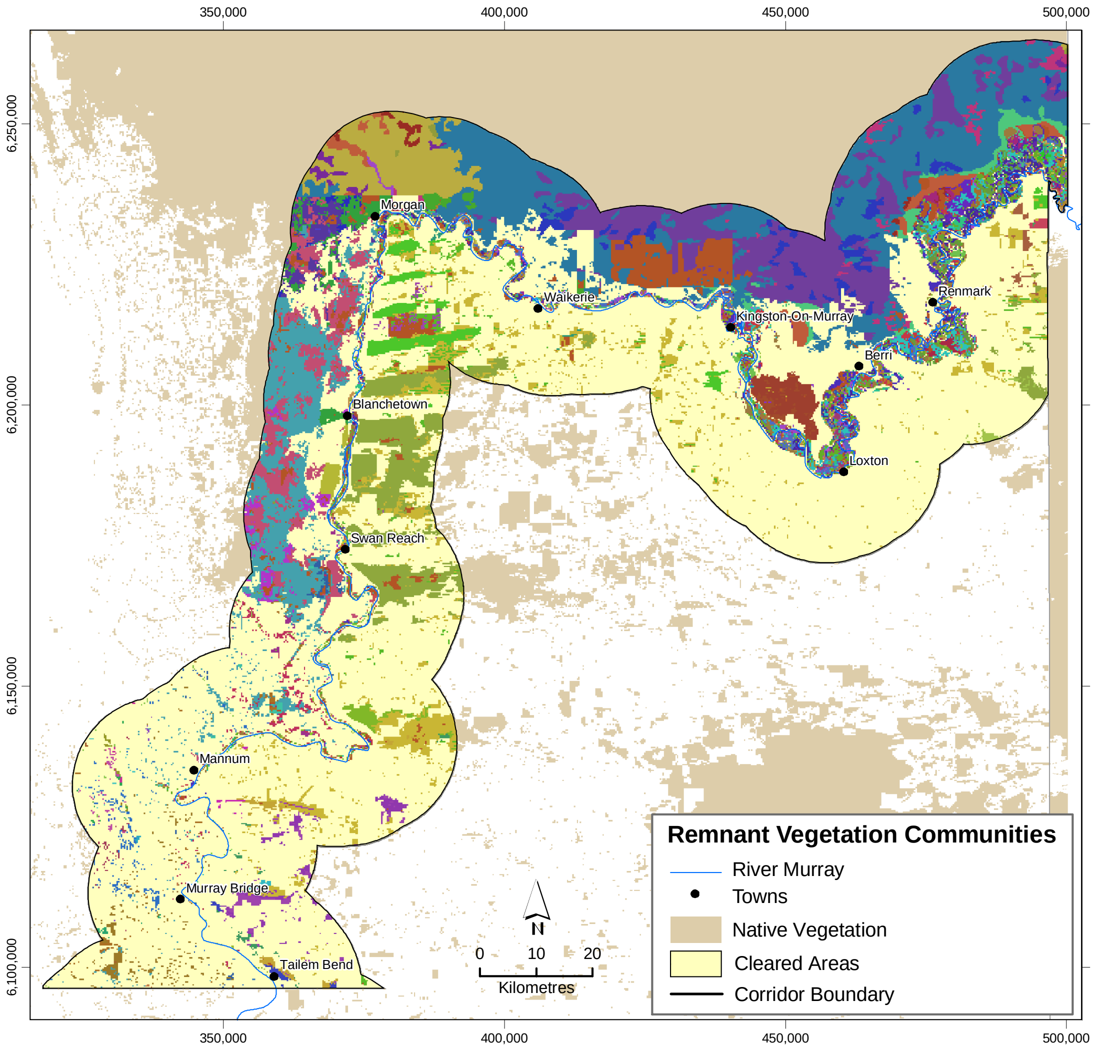

Figure 22 – Remnant vegetation communities types in the Corridor. There are too many communities to clearly distinguish but this map provides an appreciation of the spatial complexity of community distribution. The MCDA will select cells for vegetation management that include a percentage of each vegetation community.

Climate Zones

Climate is one of the main factors influencing the distribution of biodiversity, although only at relatively coarse scales. Climatic attributes such as rainfall and temperature have long been used as surrogates for characterising the distribution of biodiversity (Nix 1986). Species fundamental niche is influenced by climate because climate is a main determinant of species resource requirements. Climate zones were created for the entire SA MDB INRM region using a very simple classification of mean annual precipitation and mean annual temperature and then clipped back to the Corridor. BIOCLIM was used to create mean annual precipitation and mean annual temperature surfaces for the whole SA MDB. Mean annual rainfall ranges from 201 mm in the north of the SA MDB to 958 mm in the southern Mt. Lofty Ranges (Figure 23). Mean annual temperature ranges from 11.6 to 17.4 ^{o}C in the region (Figure 24). The precipitation and temperature surfaces were classified into 5 equal interval classes (Table 8) and overlaid to find zones of unique precipitation and temperature classes. A total of 17 climate zones occur in the SA MDB but only 8 of these occur in the Corridor (Figure 25).

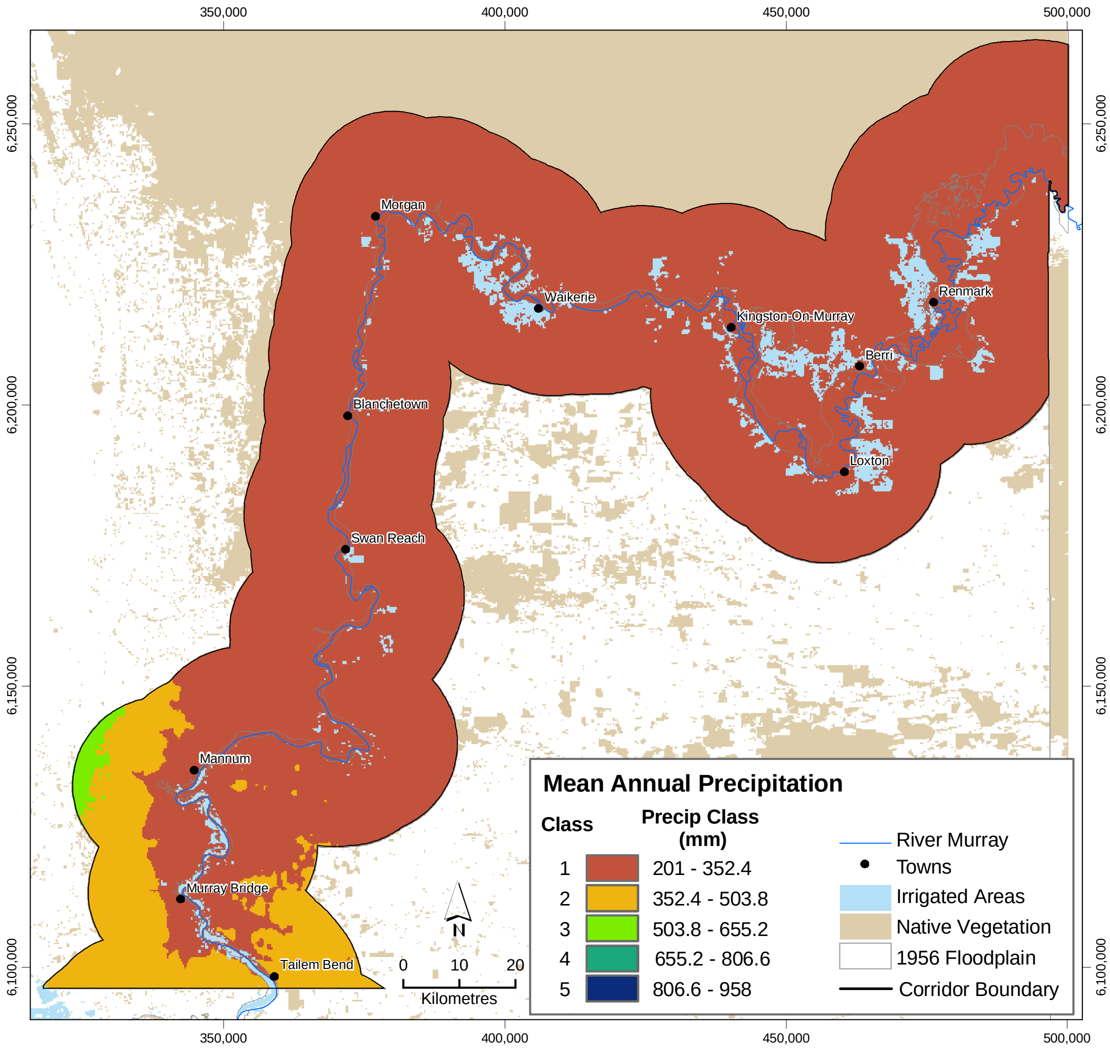

Figure 23 – Mean annual precipitation. Note that class breaks are selected based on the entire SA MDB and some classes may not occur in the Corridor.

Class	Precipitation Classes (mm)	Temperature Classes (deg C)
1	201 – 352.4	11.6 – 12.76
2	352.4 – 503.8	12.76 – 13.92
3	503.8 – 655.2	13.92 – 15.08
4	655.2 – 806.6	15.08 – 16.24
5	806.6 – 958	16.24 – 17.4

Table 8 – Mean annual precipitation and mean annual temperature classes based on data for the whole SA MDB INRM region used to construct climatic domains for use as a biodiversity attribute in MCDA.

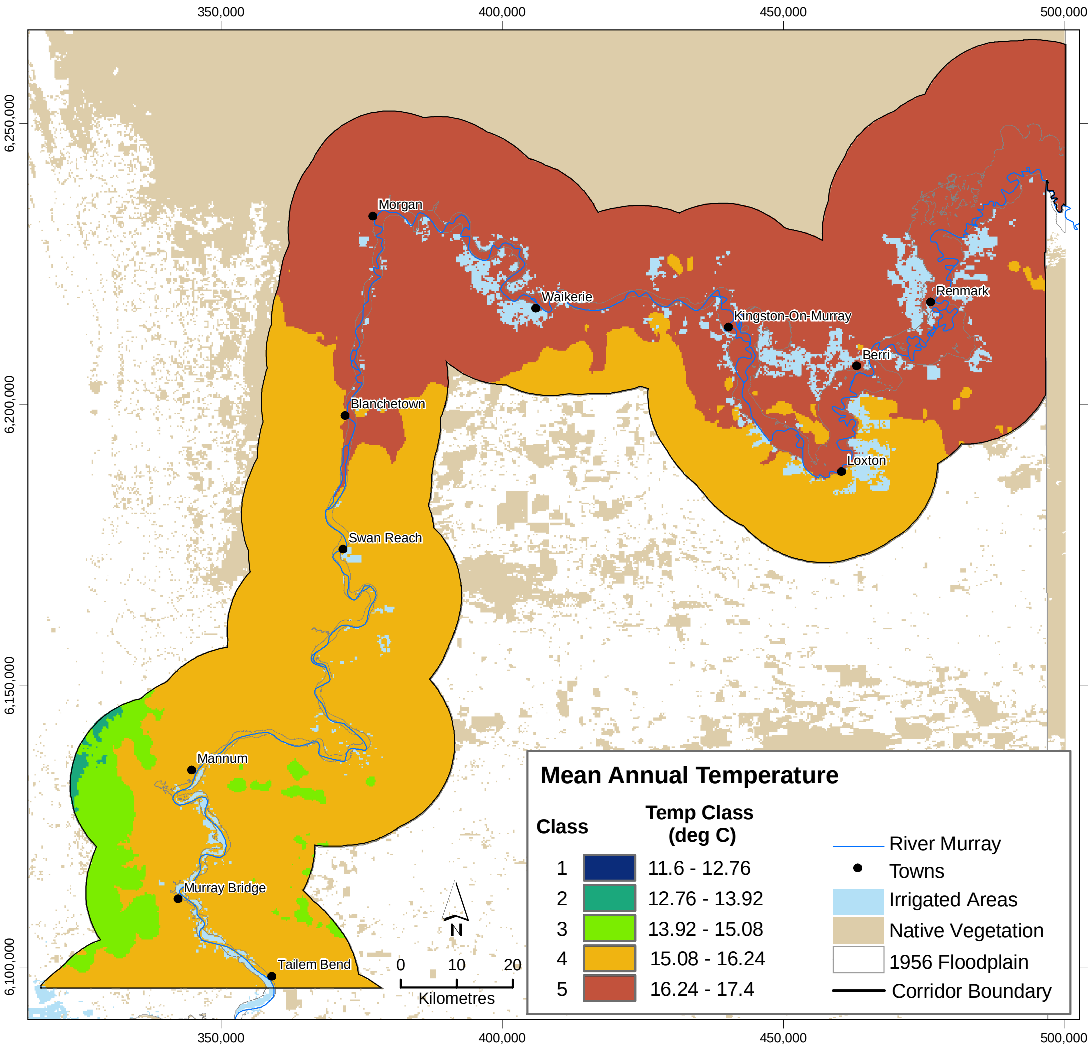

Figure 24 – Mean annual temperature. Note that class breaks are selected based on the entire SA MDB and some classes may not occur in the Corridor.

Class	Area (ha)	Temperature Class (deg C)	Precipitation Class (mm)
1	492851	15.08-16.24	201-352.4
2	3026	13.92-15.08	201-352.4
4	612579	16.24-17.4	201-352.4
6	39961	13.92-15.08	352.4-503.8
7	3045	12.76-13.92	503.8-655.2
10	62135	15.08-16.24	352.4-503.8
11	3503	13.92-15.08	503.8-655.2
12	26	12.76-13.92	655.2-806.6

Table 9 – Climate domain classes occurring in the Corridor including area of each domain and precipitation and temperature range.

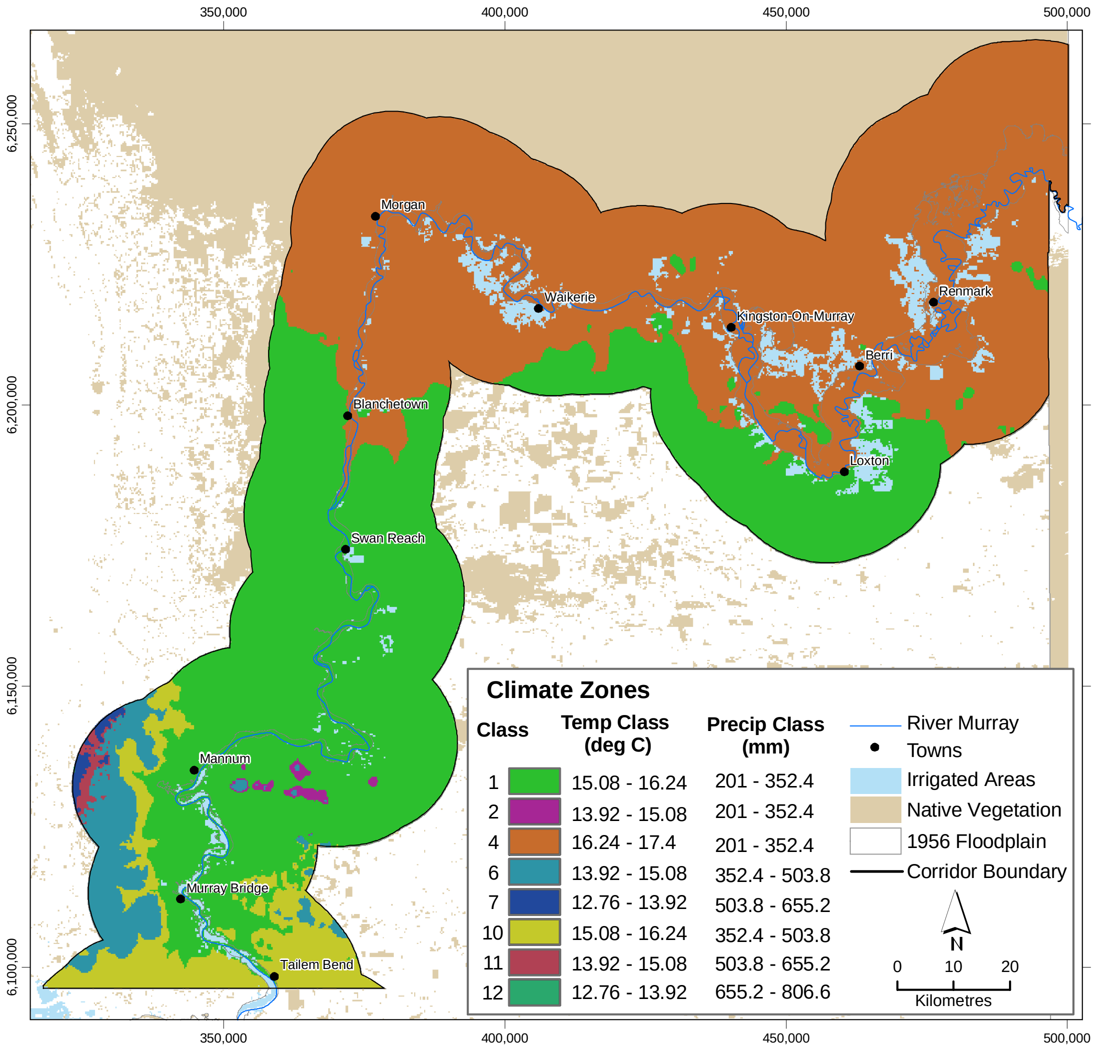

Figure 25 – Climate zones occurring in the Corridor. The MCDA will include a representative proportion of each climate zone in selecting cells for vegetation management.

Significant Fauna Habitat

Species-based approaches have been used extensively in conservation planning (Lambeck 1999, Andelman and Fagan 2000, Caro 2003, Cabeza *et al.* 2004). There are 2 main goals of species based approaches. Firstly, the goal may be to ensure the conservation of the species itself. This approach has been used when iconic species face extinction (e.g. koala) and many species recovery plans have been written to guide such a task. Secondly, individual species can be used as a surrogate or indicator for biodiversity as a whole. This approach finds currency under the umbrella species, keystone species or focal species concepts (Simberloff 1998). Species-based approaches have also been widely subject to criticism (Lindenmayer *et al*. 2002). However, if species information exists for a region, then it should be included in conservation planning to complement other types of information provided its inclusion does not unduly bias the results.

For the SA MDB INRM region the extent of suitable habitat for 21 significant fauna species has been estimated and mapped (Kahrimanis *et al*. 2001). The species are a mix of birds and mammals of conservation significance (i.e. rated on EPBC and NPWS species lists) and icon species (Kahrimanis *et al*. 2001; Table 10). The habitat extent of 11 species of significant fauna occurs in the Corridor (Figure 26). This group of birds and mammals has not been systematically selected, they do not constitute a focal group, nor are they keystone or umbrella species. However, we are taking a conservative approach to conservation in this study and the inclusion of representative proportions of the habitat of each of these significant species in MCDA can only increase the effectiveness of vegetation management in conserving biodiversity.

Species	Area (ha)	Number of Patches
Bassian Thrush	-	-
Black Eared Miner	136,296	12
Chestnut Heath Wren	-	-
Chestnut Quail Thrush	294,573	64
Common Dunnart	138,077	25
Diamond Firetail	-	-
Striated Grass Wren	187,328	31
Little Pygmy Possum	-	-
Major Mitchell Cockatoo	142,006	69
Mallee Emu Wren	-	-
Mallee Fowl	209,625	258
Mitchell's Mouse	-	-
Redlored Whistler	100,045	37
Regent Parrot	354,825	1083
Silky Mouse	-	-
Slender Billed Thornbill	-	-
Southern Hairy Nosed Wombat	943,354	312
Striped Honeyeater	374,786	146
Western Whipbird	-	-
Western Pygmy Possum	54,703	10
Yellow-tailed Black Cockatoo	-	-

Table 10 – List of 21 significant fauna species for which the spatial extent of habitat has been estimated and mapped in the SA MDB INRM region. The 11 significant species occurring in the Corridor are in bold.

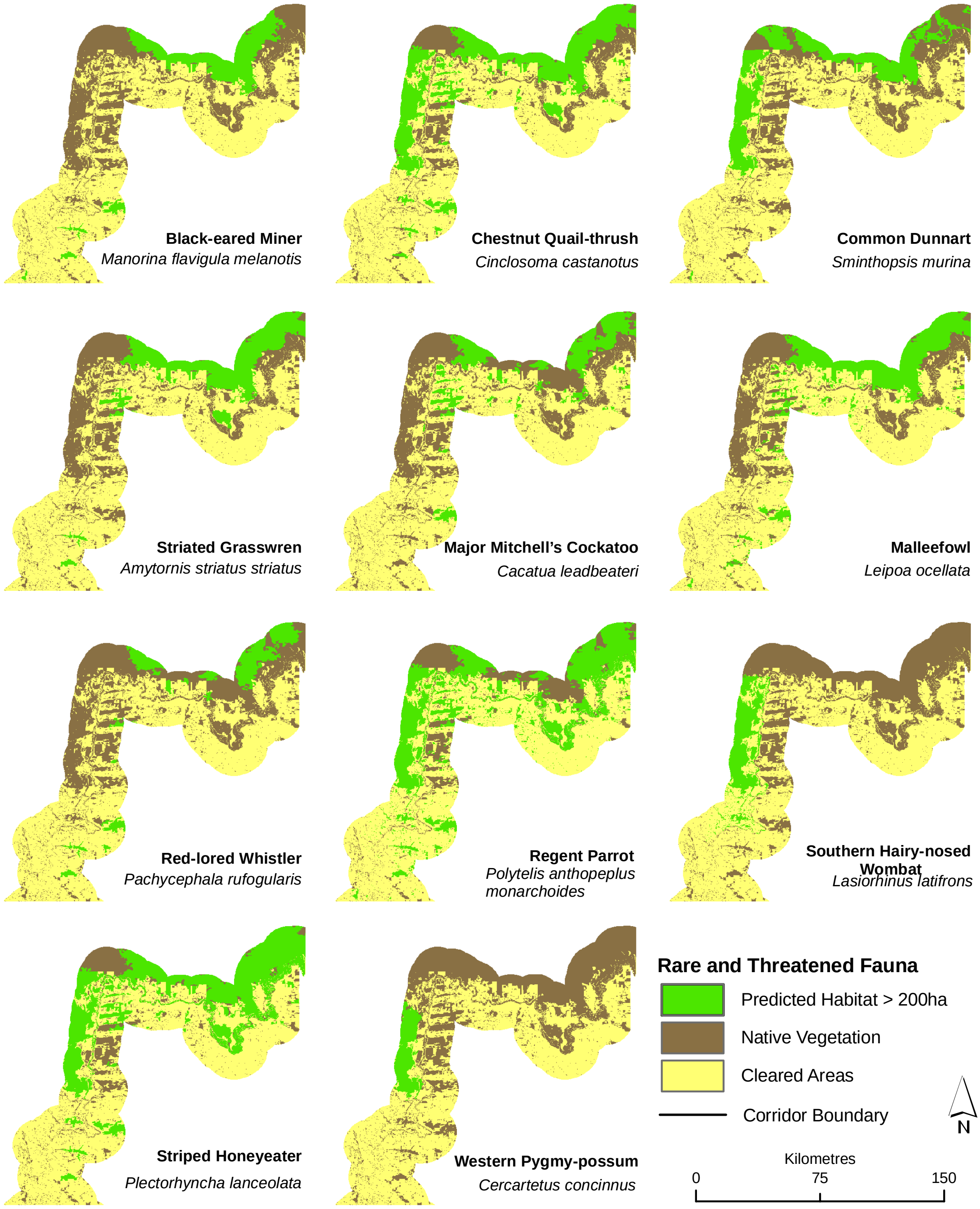

Figure 26 – Maps of the spatial distribution of significant species habitat in the Corridor.

5.1.2.1.2 Revegetation Attribute Maps

There is increasing interest in landscape-scale planning for the restoration of natural habitat for the conservation of biodiversity. By and large, the focus of recent developments remains concentrated on the restoration of the spatial structure of habitat (Loehle 1999, Wickham *et al*. 1999, Meurk and Swaffield 2000, Peterken 2000, Weber and Wolf 2000, George and Zack 2001). However, recent work has begun to extend this to consider concepts such as the restoration of ecosystem composition, diversity, structure, and function in a landscape context (Sieg *et al*. 1999, Palik *et al*. 2000, Scott *et al*. 2001). Further, some studies have begun to ask the more holistic question of what kind of patch-mosaic landscape is required for wildlife to survive (George and Zack 2001, Scott *et al*. 2001). Bryan (2003) and Bryan and Crossman (in review) use systematic conservation planning principles to set geographic priorities for revegetation for biodiversity and this is the approach we take in the Corridor.

Five biodiversity attribute maps are generated to guide geographic priority setting for the revegetation of local native species for biodiversity conservation (Table 3) with 2 attributes (Landscape Context and Fragmentation) suitable for use as costs in the objective function and 3 (Pre-European Vegetation, Climate Zones and Soil Land Systems) as targets in the constraints in spatial optimisation.

The Landscape Context and Fragmentation attributes suitable for use in the objective function are given continuously valued cost scores derived from the DEH regional floristic vegetation datasets. Again, each attribute has either integer or continuous cost scores ranging between 1 and 4 or 5 to enable numerically unbiased combination of criteria. Cost scores are based on conservation priority with highest priority given the cost score of 1 and lowest priority given the cost score of 5.

Landscape Context

It has long been recognised that patch size and isolation are fundamental factors determining species distributions and survival (MacArthur and Wilson 1967, Levin 1974, Doak *et al.* 1992. Taylor *et al.* 1993, Lindenmayer and Possingham 1996). Therefore, when considering revegetation and landscape restoration as a method for conserving biodiversity the geographic locations targeted for restoration should facilitate the expansion and linkage of remnants, particularly in fragmented and relictual landscapes (McIntyre and Hobbs 2000). We use a simple linear distance function to prioritise sites that buffer and link remnant patches of native vegetation. The distance from each non-vegetated dryland grid cell in the Corridor to the nearest remnant vegetation patch is calculated and this distance is rescaled to create cost scores between 1 and 5. Cells closest to remnant vegetation have the highest priority for revegetation and are given cost scores of 1. Cells furthest away from remnant vegetation have lowest priority for revegetation and are given cost scores of 5 (Figure 27).

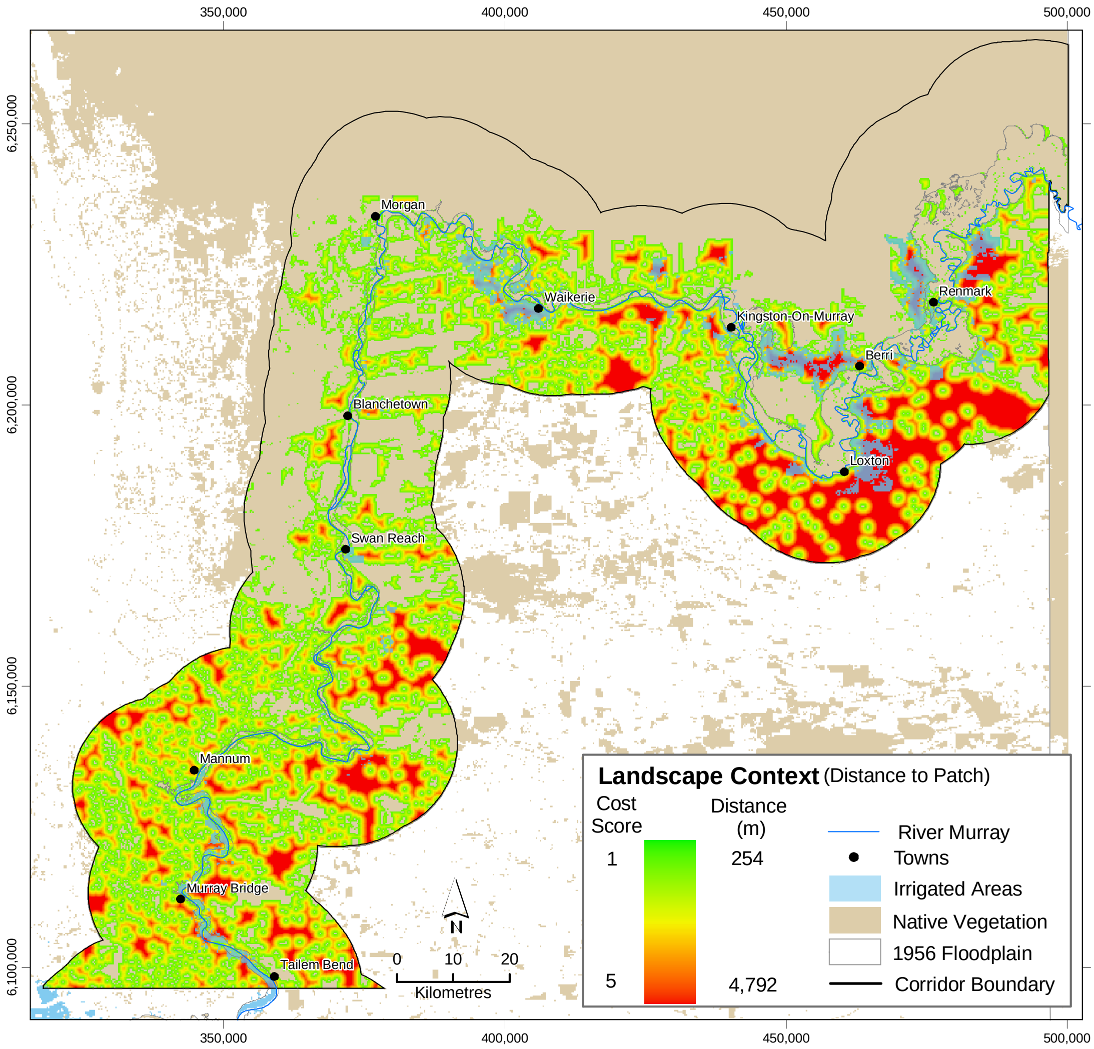

Figure 27 – Landscape context. Distance from dryland non-vegetated cells to the nearest vegetated cell linearly rescaled to values between 1 and 5.

Fragmentation

McIntyre and Hobbs (1999, 2000) prescribe priorities for vegetation management and revegetation for biodiversity conservation in the landscape given various stages of fragmentation. In this study we need to identify geographic priorities for meeting revegetation targets based on the fragmentation of remnant vegetation. Based on the discussion of McIntyre and Hobbs (1999) we consider that if revegetation is to occur in a landscape it is probably most benefit in fragmented landscapes, then relictual, variegated and lastly, intact landscapes. The fragmentation status of each dryland non-vegetated cell in the Corridor is calculated using the same method as for vegetation management by calculating the percentage of remnant vegetation in a 5km radius around each cell. The four McIntyre and Hobbs (1999) states of fragmentation are defined according to the percentage area of native vegetation remaining in the neighbourhood. Cells are ranked according to management priorities recommended by McIntyre and Hobbs (2000) such that fragmented cells receive a cost score of 1, relictual cells 2, variegated cells 3 and intact cells 4 (Figure 28).

Fragmentation Categories	% Vegetation in Neighbourhood	Cost Score	Area (ha)
Fragmented	10 – 59.9%	1	365,186
Relictual	< 10%	2	235,173
Variegated	60 – 89.9%	3	27,058
Intact	90%+	4	993

Table 11 – Fragmentation classes in the dryland areas of the Corridor.

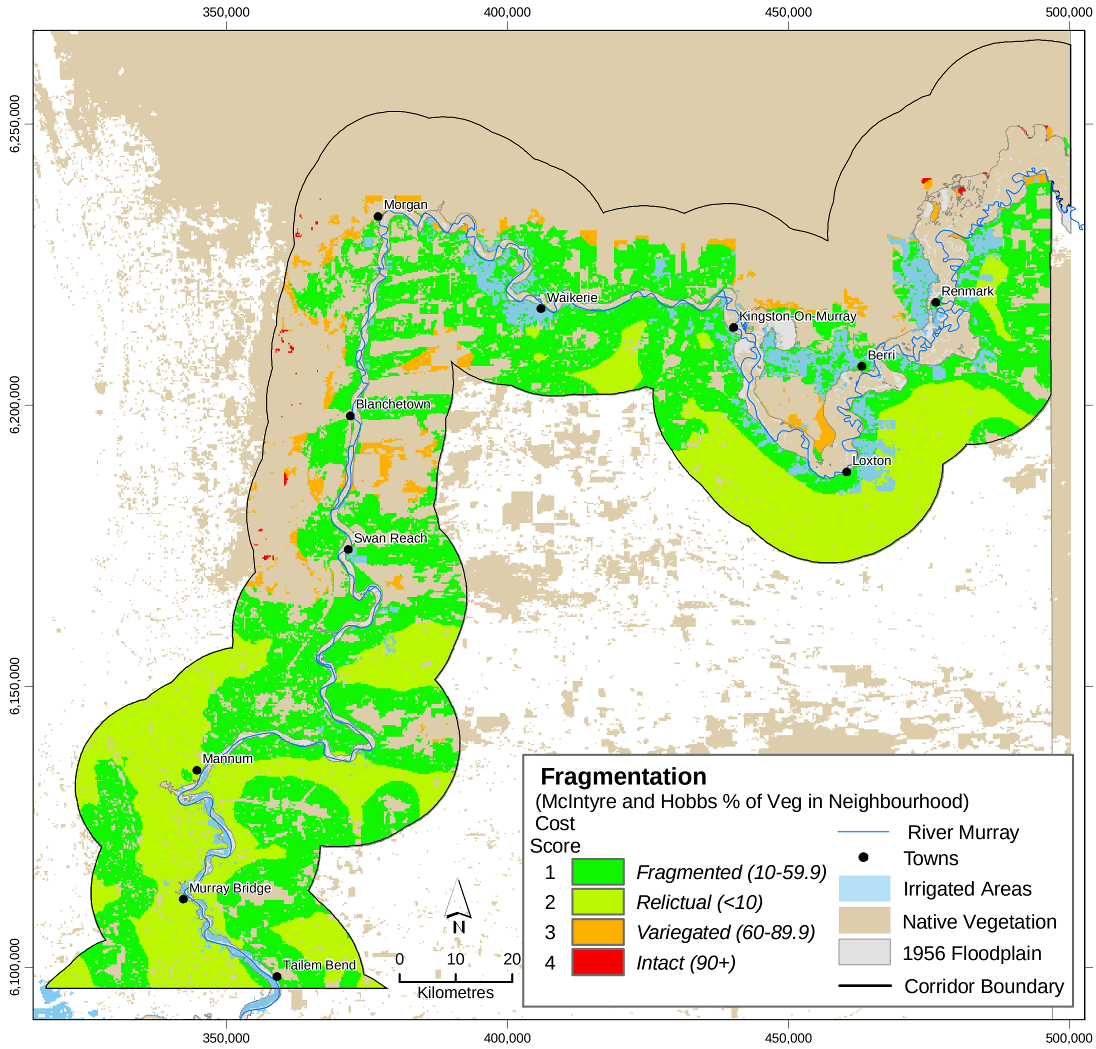

Figure 28 – Fragmentation status of dryland non-vegetated cells. Derived from the percentage of the area of remnant vegetation occurring within a 5km radius of each cell and classified based on the McIntyre and Hobbs (1999) schema for classifying landscape fragmentation.

Three categorical attributes including Pre-European Vegetation Communities, Climate Zones and Soil Land Systems have been widely used as surrogates for the distribution of biodiversity (Pressey and Nichols 1989, Bedward *et al*. 1992, Belbin 1993, Wessels *et al*. 1999). Hence, they are suitable for use as constraints for setting geographic priorities for revegetation for biodiversity in MCDA. Each attribute layer consists of categorical data (Table

3). Each attribute is again converted to a number of binary layers – one for each class where grid cells are given a value of 1 or 0 depending on whether the grid cell supports the class or not. The principle of representativeness is implemented using the constraint layers. Constraints are set for revegetation of local native species so that a certain percentage of each Pre-European Vegetation Community, Climate Zone and Soil Land System is represented by native vegetation (either remnant or revegetated). In this way revegetation efforts will address shortcomings in the representation of the existing system of remnants and provide the greatest chance of ensuring the full range of potential biodiversity has the opportunity to flourish.

Pre-European Vegetation Communities

Pre-European vegetation is a concept that attempts to describe the distribution of vegetation communities prior to broadacre land clearance by Europeans. Records of plant community composition, structure and spatial distribution are usually lacking. Pre-European vegetation maps bring together small pieces of disparate information such as herbarium records, explorers and surveyors notes, pollen records, indigenous stories, local knowledge, remnant communities and their environmental correlates (Bickford and Mackey 2004).

The pre-European community may be only one of many communities that may successfully occur on a site and the development of any one community in favour of another is significantly affected by stochastic events such as regeneration, seed source availability and disturbance history. Nonetheless, the distribution of pre-European vegetation communities is a useful surrogate for the distribution of some elements of biodiversity. Pre-European vegetation communities have been described and mapped by DEH for part of the study area. Areas to the north and west of the River Murray have not yet been mapped. For the purposes of generating the Pre-European Vegetation Communities attribute layer for MCDA, all dryland non-vegetated grid cells with no pre-European vegetation mapping were grouped into the *unknown* class and treated as a single class in the same manner as the other pre-European vegetation classes (i.e. revegetation of a certain percentage of the unknown class is also set as a constraint). A total of 22 pre-European vegetation communities have been described and mapped in the Corridor (or 23 including the *unknown* class) (Table 12; Figure 29).

Code	Pre-European Vegetation Community Description	Structure	Area (ha)
101	Allocasuarina verticillata, Eucalyptus leucoxylon ssp.over Thomasia petalocalyx, Hibbertia sericea var.,Acacia pycnantha, Dianella revoluta var.	Low Woodland	38,570
201	Casuarina pauper over Stipa sp.,Sclerolaena diacantha/uniflora,Enchylaena tomentosa var. tomentosa,Senna artemisioides ssp.	Low Woodland	5,130
601	Eucalyptus largiflorens over Stipa sp.,Einadia nutans ssp., Enchylaena tomentosa var.	Low Woodland	506
801	Callitris preissii over Stipa sp.,Enchylaena tomentosa var. tomentose	Low Open Woodland	21,292
901	Eucalyptus porosa over Stipa sp.,Lomandra effusa, Helichrysum leucopsideum,Senecio lautus, Clematis microphylla,Danthonia sp.	Low Open Woodland	6,157
1101	Eucalyptus dumosa, +/- E. leptophylla overStipa sp., Danthonia sp.,Lepidosperma congestum/laterale/viscidum	Mallee	302,198
1201	Eucalyptus cyanophylla, +/- E. socialis overSclerolaena diacantha/uniflora,Triodia irritans var.	Open Mallee	21,743
1401	Eucalyptus leptophylla, E. socialis overTriodia irritans var., Stipa sp.	Open Mallee	11,074
1701	Eucalyptus calycogona, E. dumosa overStipa sp., Danthonia sp.	Very Open Mallee	20
1801	Eucalyptus gracilis, E. oleosa overSclerolaena diacantha/uniflora, Stipa sp.,Maireana pentatropis, Zygophyllum apiculatum	Very Open Mallee	12,762,125
1901	Eucalyptus incrassata, Leptospermum coriaceumover Hibbertia riparia, Baeckea behrii, Callitris verrucosa,Glischrocaryon behrii, Melaleuca uncinata	Open Low Mallee	31,234
2802	Maireana sedifolia overEnchylaena tomentosa var. tomentosa,Eriochiton sclerolaenoides, Rhagodia spinescens,Sclerolaena obliquicuspis	Very Open Shrubland	2,029
3101	Muehlenbeckia florulenta	Shrubland	34
3301	Halosarcia sp. overDisphyma crassifolium ssp. Clavellatum	Low Very Open Shrubland	8,679
3601	Gahnia filum, Samolus repens	Sedgeland	341
3701	Lomandra effusa withLepidosperma congestum/laterale/viscidum,Asphodelus fistulosus, Cryptandra amara var.	Open Sedgeland	847
3801	Myoporum platycarpum	Low Woodland	142,461
4001	Alectryon oleifolius ssp. Canescens	Tall Shrubland	4,266
4601	Eucalyptus yalatensis, E. dumosa, E. gracilis	Mallee	10,196
4701	Eucalyptus socialis, E. Dumosa	Open Mallee	15,842
5001	Phragmites australis, Typha spp.	Sedgeland	77
5101	Eucalyptus odorata	Open Mallee	43

Table 12 – Pre-European vegetation communities mapped by DEH in the mallee areas of the Corridor.

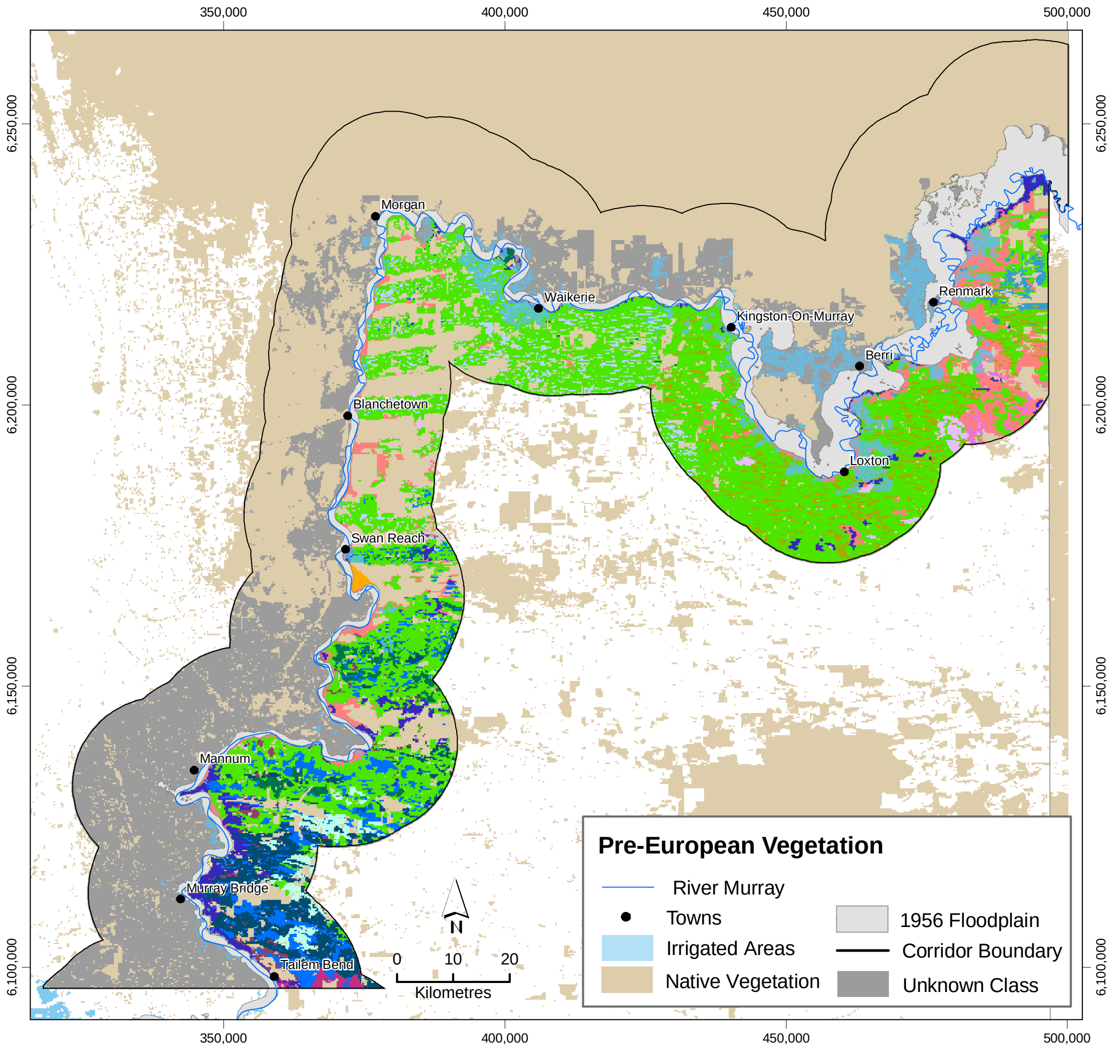

Figure 29 – Distribution of pre-European vegetation communities in the Corridor as mapped by DEH. Note: there are too many classes to be clearly represented at this scale but the complexity of spatial distribution is evident.

Climate Zones

The Climate Zones described above in Section 5.1.2.1.1are used as a constraint attribute for revegetation. Revegetation needs to be prioritised with the aim of having remnant vegetation and revegetated areas representing the full range of climate zones in the Corridor. Some climate zones such as the hot, dry regions north of the stretch of river between Waikerie and the border are well represented by existing remnant vegetation. However, other climate zones, such as the more productive wetter, cooler climates of the eastern Mt. Lofty Ranges may require significant amounts of revegetation to bring the total amount of vegetation (remnant and revegetated) up to the required level of representation.

Soil Land Systems

Soil data is commonly available for many regions especially if agriculture is a potential land use in the region. This is because information on the spatial distribution of soil characteristics can be used to estimate the agricultural capability of land and is an important precursor for modern agricultural development. Soil information is also a useful surrogate for the distribution of biodiversity (Oliver *et al*. 2004). Oliver *et al*. (2004) found differences in the biota supported by different land systems. Hence, in planning for the restoration of biodiversity through revegetation of local native species, the full range of land systems should be represented either by remnant vegetation or targeted for revegetation.

Soil land systems have been mapped for the majority of the study area and all of the cleared dryland areas of the Corridor. The South Australian Department of Primary Industries and Resources (PIRSA) has spent many years mapping soils. The elemental unit of PIRSA's soil survey is the Soil Landscape Unit. Each Soil Landscape Unit occurs within a broader Soil Land System. The Soil Land System mapping is used in this study as a surrogate for biodiversity to set priorities for revegetation. There are 60 Soil Land System classes in the non-vegetated dryland areas of the Corridor. Areas that have not been classified have been grouped into an *unknown* class and treated the same as other mapped classes in MCDA (Table 13, Figure 30).

Code	Land System	Area (ha)	Code	Land System	Area (ha)	Code	Land System	Area (ha)
164	URB	1729	394	NOO	3200	533	REE	3497
211	FLR	1523	422	MAN	12464	534	BUR	81445
288	BCP	232	444	SED	135	536	NAR	2232
297	EBA	8690	466	RAT	948	545	PAL	5858
298	TIG	1600	477	NAH	12168	556	WHH	9458
316	UMV	13561	482	ROC	3677	557	DIH	3529
317	MUT	6077	486	MRN	2787	564	EMU	1961
319	PGK	27355	487	KUN	20052	568	WYN	90
320	BNY	6	489	BLH	1690	578	KIN	5503
326	LMV	16084	493	AVA	2187	579	MOA	4045
327	CAD	1794	499	STN	8394	594	MNS	3277
336	MSH	929	503	SAU	5219	598	MAJ	3471
340	BLT	22961	507	BAN	13368	599	GIH	6806
342	MUR	29929	509	NOB	4400	600	BRK	14658
344	HOL	98858	514	TUN	3665	603	HAR	3955
345	LOX	111284	515	MID	1181	604	JER	3058
351	MRD	7761	516	BOR	561	610	SHE	4729
361	OLC	1839	522	RID	2723	615	LHC	135
371	BMR	2987	525	PUN	7516	616	MAL	490
388	COH	832	527	APA	5413	618	MOS	232

Table 13 – Area of the 60 Soil Land Systems occurring in the dryland areas of the Corridor. The Land System code refers to PIRSA mapping codes. The area of unknown Soil Land System is 80,180 ha.

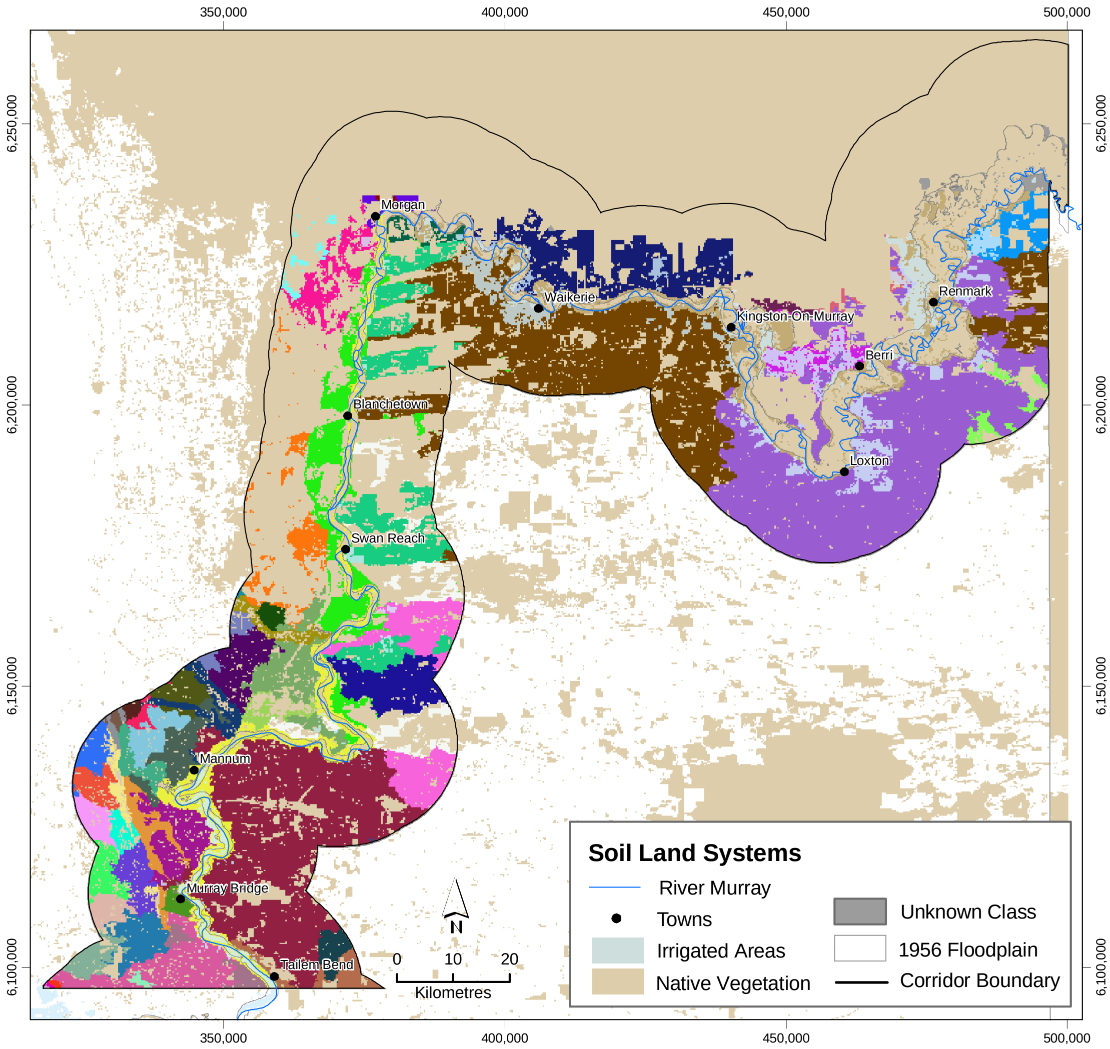

Figure 30 – Distribution of Soil Land Systems in the Corridor as mapped by PIRSA. Note: there are too many classes to be clearly represented at this scale but the complexity of spatial distribution is evident.

5.1.2.2 Costs of Vegetation Management and Revegetation for Biodiversity

The cost of undertaking any NRM activity is highly variable from one location to another due to the heterogeneous nature of the landscape and the ecosystems it supports. The fundamental question facing all natural resource managers is how to achieve the maximum benefit from the limited funds available to undertake NRM activities. Within the Corridor the diversity of factors influencing the cost of NRM activities in particular locations is complex. We attempt to simplify this complexity and provide an assessment of the range of possible costs involved in improving biodiversity through vegetation management and revegetation with local native species. In this study vegetation management occurs where some form of remnant vegetation exists and revegetation occurs in situations where the land has been previously cleared. Under a broader context these activities have three major components:

1. **Fencing** – fencing a patch undergoing either vegetation management or revegetation, fencing is a necessary action if the patch is subject to stock grazing or, in the case of revegetation, rabbit invasion. For stock control we have elected to use the most common types of fencing, those being:
    i.) Five strand ring lock fencing to 900mm high with a pine post every 9m and two droppers at 3m intervals. This is commonly referred to as sheep and lamb fencing. Allowances have been made for gates at a rate of one gate per 5km of fencing for fences up to 10km in length or one gate for every 10% of total fence length for fences over 10km in length inclusive of all hinges and mountings.
    ii.) Five strand wire fencing with two barbed upper strands. A pine post every 20 meters with three droppers in between. This is a common fence for livestock such as cattle. Allowances have been made for gates at a rate of one gate per 5km of fencing for fences up to 10km in length or one gate for every 10% of total fence length for fences over 10km in length inclusive of all hinges and mountings.

    The fence for rabbit control should be wire netting to 700mm high with 120-150mm rolled flat on the ground on the outside of the fence and staked every 5m. Costs of fencing are listed in table 14. The low cost estimates are for materials only and assume the fence will be erected with *"in kind"* contributions. The high cost estimates are for materials and contractor time to erect.

Stock exclusion	**Fencing type**	**Low ($ per linear metre)**	**High ($ per linear metre)**	**Gates ($)**
Soil substrate	Rabbit	8	15	200
	Ringlock	3.50	5	200
	Cattle	3	4.50	200
Rocky substrate (i.e. Limestone	Rabbit	14	21	200
	Ringlock	9.50	11	200
	Cattle	9	0.50	200

Table 14 - Estimates of costs of fencing per linear metre. Source (Coopers Rural and Hardware Supply, pers. comm., 2005; David Hein, Trees for Life, pers. comm., 2005; Mitchell Fencing, pers. comm., 2005)

2. **Revegetation** – there are three types of revegetation considered in this study all of which have advantages and disadvantages. The expected outcomes of each of these actions can and does vary from site to site depending on the climatic conditions of the site, the suitability of the site, the viability of the seed supplied or quality of the tube stock and the skill of the operators.

    i.) **Natural regeneration** – in situations where the proposed site is within 1km of some remnant vegetation, protecting the site from rabbits or stock can result in effective regeneration of the local native species via natural dispersal of propagules. Where the patch of remnant vegetation is in good condition or better, the longer-term biodiversity outcomes (i.e. 30+ years) are more likely to resemble those of the remnant patch. Effective management of natural regeneration can result in both the lowest cost option as well as the greatest biodiversity outcomes.

ii.) **Direct seeding** – in situations where the site is readily accessible and the clay content of the soil is not too high, direct seeding is generally an effective option. Gaining access to a suitable quantity of viable seed is usually the greatest impediment to this method of revegetation as it may be necessary to use as much as five kilograms of seed for each hectare (David Hein, Trees for Life, pers comm. 2005). However when the seed is dispersed in a mixed form the resulting germination allows the processes of competition to encourage vegetation structure more similar to natural regeneration than tube stock planting. Over the longer term (i.e. 30+ years) the expected biodiversity outcomes can vary dramatically depending on the diversity and success of the seeding, the proximity to other patches of remnant vegetation. Direct seeding is generally more effective in sandier soils. Where the clay content of the soil is quite high revegetation with tube stock is generally more successful.

iii.) **Planting of tube stock** – tube stock planting is the preferred option where access is difficult (i.e. steep river banks or gullies) or where infill planting is required, and natural regeneration is likely to be impeded. Effective survival rates rely on correct planting techniques. Survivability can be up to 80% when correct planting techniques are used, supplied tube stock is vigorous and healthy, and pests are effectively controlled. Although technological improvements have led to increases in the cost efficiency of tube stock planting, it can still be an expensive exercise because of the high cost of inputs (labour and materials). Tube stock planting may however, complement direct seeding approaches.

Table 15 lists the upper and lower cost estimates for revegetating with tube stock and direct seeding. Natural regeneration has no direct costs. The low cost option for tube stock planting assumes a large degree of *in-kind* contributions and the high cost options are based on contractor costs.

Tube stock revegetation previously grazed	**Price ($) per stem**		**Price ($) per ha at 1m centres**	
	Low	**High**	**Low**	**High**
Site Preparation	0.10	1.50	100.00	1,500.00
Plant Supply	0.06	1.50	60.00	1,500.00
Planting	0.00	2.00	0.00	2,000.00
Aftercare	0.10	1.50	100.00	1,500.00
Total	0.26	6.50	260.00	6,500.00
Direct seeding revegetation previously grazed	**Without Site Preparation**		**With Site Preparation**	
	Low	**High**	**Low**	**High**
	100.00	500.00	200.00	800.00

Table 15 - Estimates of costs of revegetation activities. Source (David Hein, Trees for Life, pers. comm. 2005)

3. **Bushcare/weed control** – estimating the cost of weed control activities is a difficult task. Control efficacy is reliant on the skills of the operators and their knowledge of the correct methods, materials and timings. Application of incorrect weed control

methods can result in a biodiversity reduction. For example actively spraying a non-aquatically safe glyphosate product across a water course can kill or damage aquatic species such as fish, frogs or macroinvertebrates. For this reason, costs are derived from operators who are actively used by natural resource management groups such as the River Murray Catchment Water Management Board or the Riverland Plant and Animal Control Board. Table 16 outline the costs of undertaking weed control works in patches of remnant native vegetation with varying degrees of weed infestation and patch disturbance.

	Level of infestation					
Level of disturbance	**Low**		**Moderate**		**High**	
	Low ($)	High ($)	Low ($)	High ($)	Low ($)	High ($)
Low	912	1,936	1,140	2,640	1,710	3,520
Moderate	684	1,496	1,026	2,288	1,425	2,992
High	342	880	570	1,584	855	2,376

Table 16 – Upper and lower estimates of the cost of weed control activities for areas of different levels of weed infestation and ecosystem disturbance from clearance or grazing. Costs are inclusive of materials and labour. Source (Riverland Animal and Plant Control Board, pers. comm. 2005, Tony Golder, Spray Contractor, pers. comm., 2005)

The range of possible costs vary on a site-by-site basis depending on the biophysical characteristics and the threats operating at the site (e.g. the level of weed infestation and the degree of disturbance of the native community). For vegetation management the low cost alternatives assume that only weed control is required. Table 17 lists the combined figures from Table 14 and Table 16. The low cost options include the cost of weed control only and the high cost options include the cost of weed control and fencing. The high cost options assume that both weed control and a rabbit proof fence in rocky or limestone substrate are required.

	Level of infestation					
Level of disturbance	**Low**		**Moderate**		**High**	
	Low ($)	High ($)	Low ($)	High ($)	Low ($)	High ($)
Low	912	10,536	1,140	11,240	1,710	12,120
Moderate	684	10,096	1,026	10,888	1,425	11,592
High	342	9,480	570	10,184	855	10,976

Table 17 - Estimates of the costs of vegetation management per hectare for areas of different levels of weed infestation and ecosystem disturbance from clearance or grazing.

For revegetation, all sites assume an open or cleared paddock located near a patch of remnant vegetation in reasonable condition. It has also been assumed that the low cost alternative requires boom spraying only and the high cost alternatives require boom spraying and a rabbit proof fence in rocky or limestone substrate. Table 18 outlines high and low estimates of the costs of undertaking each of the three revegetation alternatives.

Natural Regeneration		Direct Seeding		Tube stock	
Low ($)	High ($)	Low ($)	High ($)	Low ($)	High ($)
33	8,665	200	9,400	260	15,100

Table 18 - Estimates of the cost of undertaking revegetation per hectare.

The above discussion outlines all of the many factors involved in the costs of both vegetation management and revegetation. It is a difficult step then to take this complexity and use it to make estimates of the total cost of meeting regional resource condition targets through these NRM actions. To make an accurate assessment more information is required on such things as the length of fencing required, the distribution of rabbits, limestone substrate, and the level of disturbance of native communities, the distribution and level of threat of weed invasion, and also the preference for different revegetation types. Nonetheless, we can use this information to make low and high estimates of the average price per hectare of vegetation management and revegetation in the Corridor in order to estimate the total cost of establishment of these NRM actions.

Cost estimates are similar for vegetation management and revegetation activities. Past rates of funding can help us estimate the costs of vegetation management and revegetation. Low estimates for revegetation which have involved direct seeding, no fencing and minimal weed control are around $300/ha. Average figures are around $300 - $500 per ha excluding fencing (Graham Gates, Project Officer, Coorong District Local Action Planning Group, pers. comm. 2005). To estimate the total establishment costs of vegetation management and revegetation in meeting resource condition targets in the Corridor in this study we use a low estimate of $500 per hectare and a high estimate of $3,000 per hectare.

5.1.3 Opportunity Costs

Opportunity costs are the costs of foregone income from agricultural land uses such as grazing and cereal cropping. A layer of opportunity costs is a necessary attribute in the MCDA to identify the least expensive locations for vegetation management and revegetation actions. In this study opportunity costs are calculated based on the current value of agricultural production. The real opportunity costs may be much greater than those modelled, especially in cases where agricultural land adjoins expanding townships and the potential real estate value is greater than the current agricultural production. Dryland agriculture close to existing irrigation infrastructure and near rapidly expanding irrigation developments may also have greater value than the current value of agricultural production. However, these issues are not considered in this study.

Opportunity costs were mapped in a sequence of steps. Initially, the spatial distribution of dryland agriculture was quantified and mapped using the DWLBC catchment scale land use mapping. Despite having a lower commodity resolution that Bryan and Marvanek (2004), the DWLBC catchment scale mapping is used because of its higher spatial resolution. DWLBC land use mapping classifies land parcels according to the Australian Land Use and Mapping Classification standard Version 4 (ALUMC V.4).

Land use classes were then generalised to 5 categories of dryland land use: Cereals; Grazing; Hay & Silage; Legumes; and Other Minimal Use (Figure 31). The Cereals class includes ALUMC V.4 classes of cereals and cropping, and the Grazing class includes the ALUMC V.4 classes of grazing native vegetation and grazing modified pastures. All native vegetation on private land is considered to be under the agricultural landuse of grazing and to have the same opportunity cost as grazing.

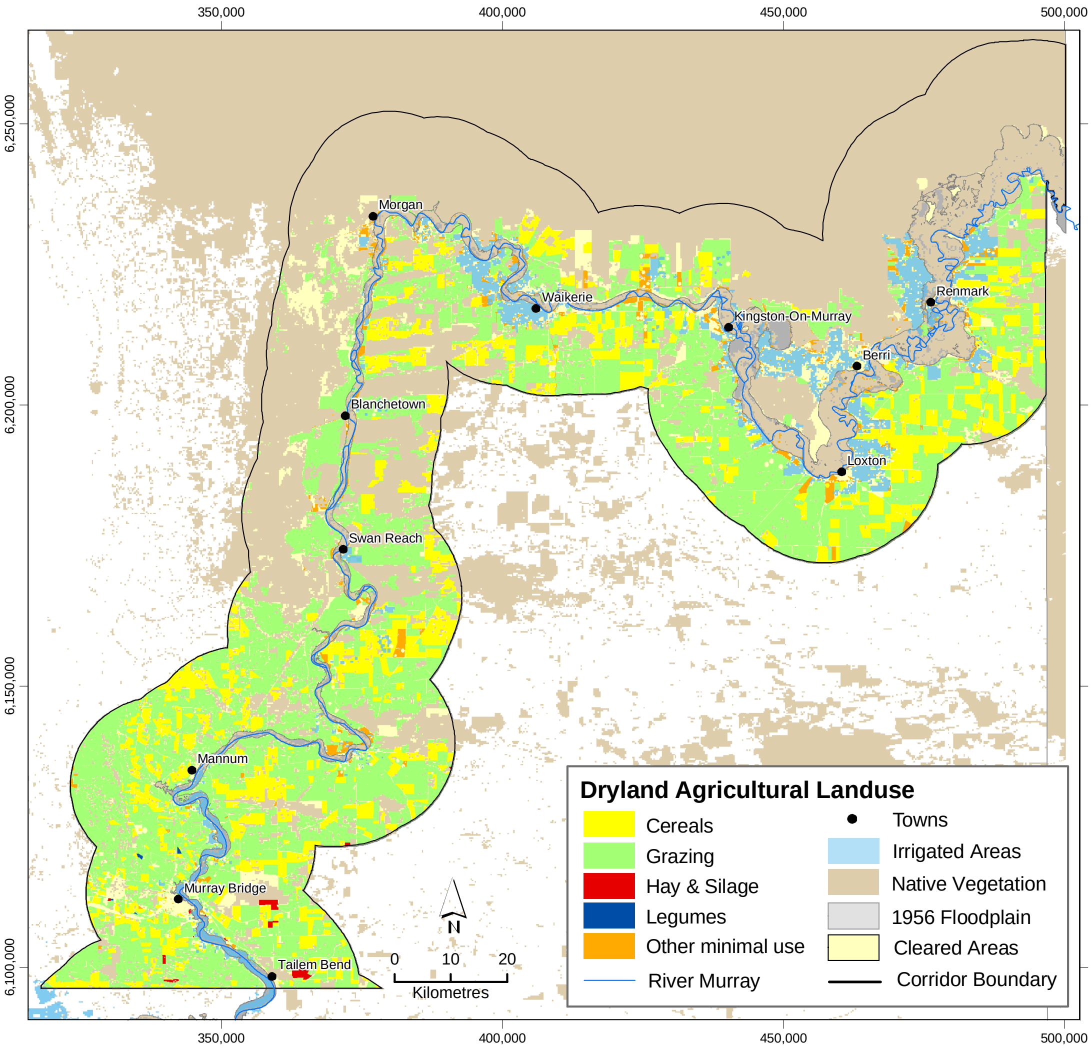

Figure 31 – Dryland agricultural land use in the Corridor.

Each class was given an average gross margin (GM) in present value terms for the region based on figures from Sadras (2004), Bryan and Marvanek (2004) and Ward and Trengove (2004):

- Cereals $80/ha
- Grazing $37.50/ha
- Hay & silage $150/ha
- Legumes $120/ha
- Remnant vegetation on private land $15/ha
- Other minimal use $10/ha

The spatial extent of dryland agriculture mapped by DWLBC differs from the SIMPACT modelling and other parameters in this study. Spatial operations were used to estimate the opportunity costs for areas not mapped as dryland agriculture by DWLBC. These cells were given the opportunity cost of the nearest cell mapped by DWLBC.

Although soil quality and other factors have a strong influence, the primary driver of dryland agricultural productivity in the Corridor is rainfall. There exists a steep climatic gradient over the Corridor study area (Figure 23; Figure 24). Similar dryland agriculture types can return very different gross margins depending on the rainfall. Hence, in order to gain better representation of opportunity costs, average gross margin figures were redistributed following the spatial distribution of rainfall. Gross margin figures for each grid cell were adjusted using the ratio of the mean annual precipitation of the cell to the average mean annual precipitation of the SA MDB region (300 mm/yr). The mean annual precipitation layer was modelled using BIOCLIM (Figure 23). As a result, agricultural land uses in drier climates were attributed lower opportunity costs and land uses in moister climates were attributed higher opportunity costs (Figure 32).

Opportunity costs of dryland agriculture as modelled in this study range from $7.83/ha to $199.00 per hectare with a mean of $46.53 and a standard deviation of $22.54. The total economic returns to agriculture in gross margin terms and hence, the total opportunity costs to agriculture in the Corridor as calculated using the methods described above is $29.25 Million per year. This amount of gross margin agrees well with the $21.4 Million in returns to agriculture found by Bryan and Marvanek (2004) when they estimated profit at full equity. Opportunity costs are linearly rescaled to values between 1 and 5 for input as an attribute in MCDA (Figure 32).

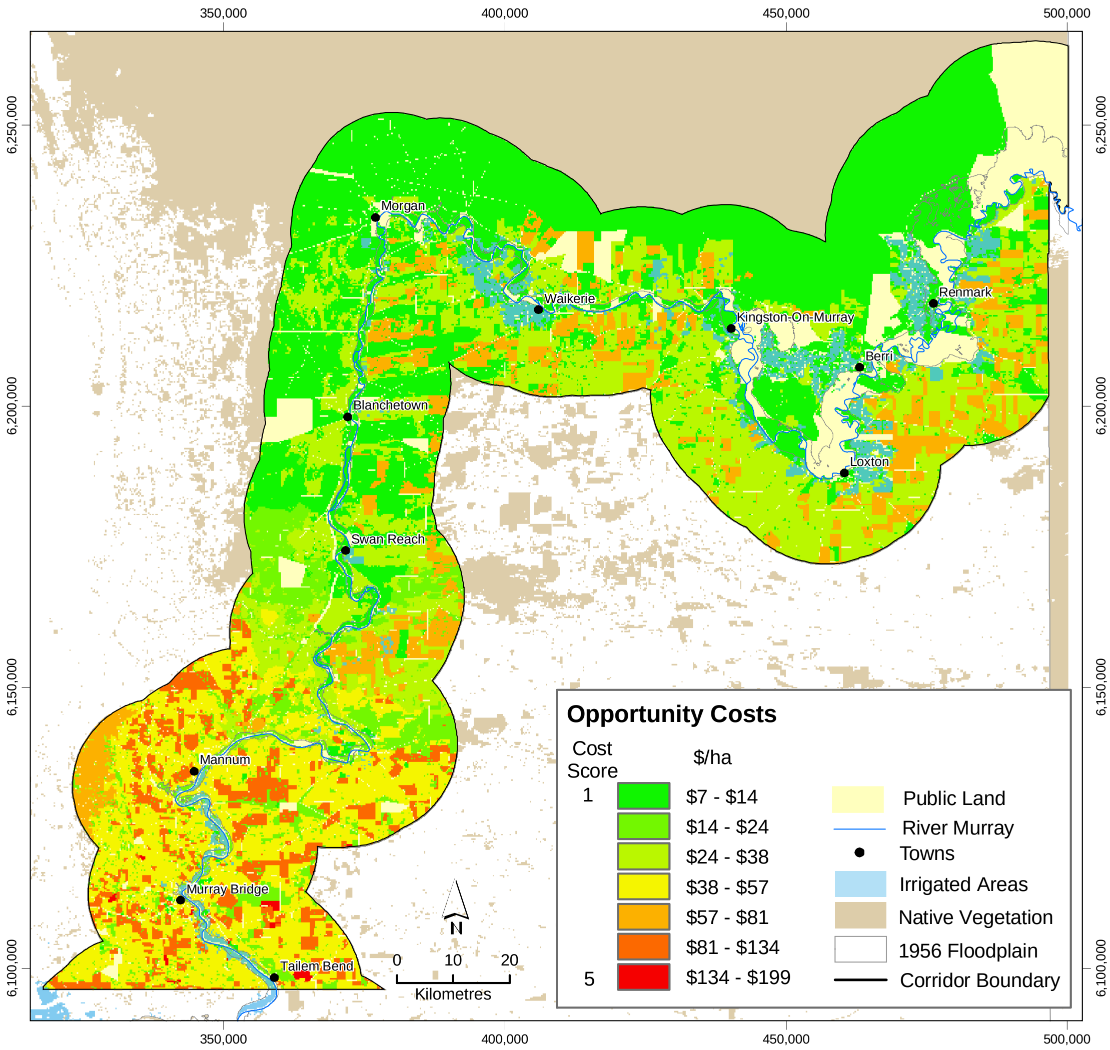

Figure 32 – Opportunity costs in the Corridor based on land use, climate and estimated gross margin values. Note that 7 classes are used in this map to aid visual interpretation. Costs scores are continuously valued between 1 and 5.

5.1.4 Biomass

A significant amount of research has examined the potential for the broad-scale production of *Eucalyptus* species for biomass industries in southern Australia and elsewhere (Rozakis *et al*. 2001), in particular, for Integrated Tree Processing (ITP). Ellis (2001) provided an early assessment of the potential for biomass production in the low rainfall agricultural areas of South Australia. Enecon (2001) and Howard and Olszak (2004) found that an ITP plant is potentially economically viable in southern Australia and the Enecon (2001) study led to the implementation of the trial ITP plant at Narrogin in Western Australia. Ward and Trengove (2004) and Howard and Olszak (2004) review the market opportunities for the products of an ITP including renewable energy, oil and activated charcoal. Ward and Trengove (2004) found that the broadacre production of biomass and processing in an ITP plant is a potentially viable economic proposition on both sides of the production system. In this part of the study we generate attribute maps of the spatial distribution of the economic profitability of biomass for landholders in the Corridor over time and provide a comprehensive assessment of the sensitivity to the model parameters.

In an exhaustive search, Bennell *et al*. (2004) found that the best species for supplying biomass to an ITP plant in the Corridor are *Eucalyptus oleosa* and *Eucalyptus porosa*. In this study we assess the economics of revegetating areas in the Corridor with *Eucalyptus oleosa* to supply an ITP plant, compared to current agricultural production. Economic and financial measures are calculated to provide some sense of the profitability of biomass to farmers. This work integrates strongly with the FloraSearch (Bennell *et al*. 2004) and Biomass (Ward and Trengove 2004) projects and builds significantly upon them.

Maps of biomass profitability were developed using the spatially varying parameters of biomass productivity, opportunity costs, travel costs and scalar parameters including harvest costs, maintenance costs and fertiliser costs. Costs and returns to biomass occur at irregular intervals so the economic analysis is conducted in net present value terms. Maps of economic indicators of biomass profitability become attributes for input into the MCDA model.

5.1.4.1 Methods

Economic analysis of agricultural and forestry enterprises should consider the timing of costs and returns to the enterprise in the context of people's time preference. This is particularly relevant for biomass production because it involves significant up-front establishment costs, some delay until first harvest, and regular harvest at 3 yearly intervals. People's time preference is founded on the premise that any future value is equivalent to some current sum of money invested at a certain percentage interest rate and a certain rate of inflation, and is dependent upon their attitude to risk. Time preference is usually incorporated in economic analyses using discounting. This involves the use of interest (or discount rates) that discount future sums of money (both costs and revenue) compared with those of today. The economic measures of Net Present Value (NPV), Modified Internal Rate of Return (MIRR) and Equal Annual Equivalent (EAE) incorporate irregular cash flow and time preference (Jacobson 1998) and are used to assess the economic potential of biomass industries in the Corridor.

Economic analysis of biomass in the Corridor involves calculation of the revenue from biomass and the costs of production over some time frame. Hobbs (pers comm. 2004), based on Bennell *et al*. (2004), suggests that the optimal harvesting regime for *E. oleosa* in the Corridor is a 6-year establishment period followed by three-yearly harvests. Harvest involves coppicing of the plant near ground level from which it will reshoot. *E. oleosa* does not need replanting after harvest thereby saving a significant cost and delay in waiting for the new crop to become established. In normal production, the ITP plant needs a constant supply of 100,000 green tonnes of biomass each year. To provide this amount we assume the staggered planting regime of one third of the crop planted at the beginning of year 1, one third in year 2 and the final third in year 3. We also assume a staggered harvest after the 6-year establishment period of one third of the crop harvested each year and each hectare of land harvested every three years. Immediately following harvest the biomass crops require fertilisation. The crops also require minimal annual maintenance.

In modelling the economic potential of biomass as attribute maps for MCDA we need to characterise returns from and costs of production. This production regime involves irregular cash flow. Revenue and costs of biomass production are calculated for each year based on this production schedule and discounted back to net present value terms. Revenue from biomass production occurs first in year 6 and then regularly each year after that as one third of the crop is harvested each year. The costs of biomass production include establishment costs, maintenance costs, harvest costs, fertiliser costs, opportunity costs, and transport costs. Different costs occur at different times in the production schedule (Figure 33).

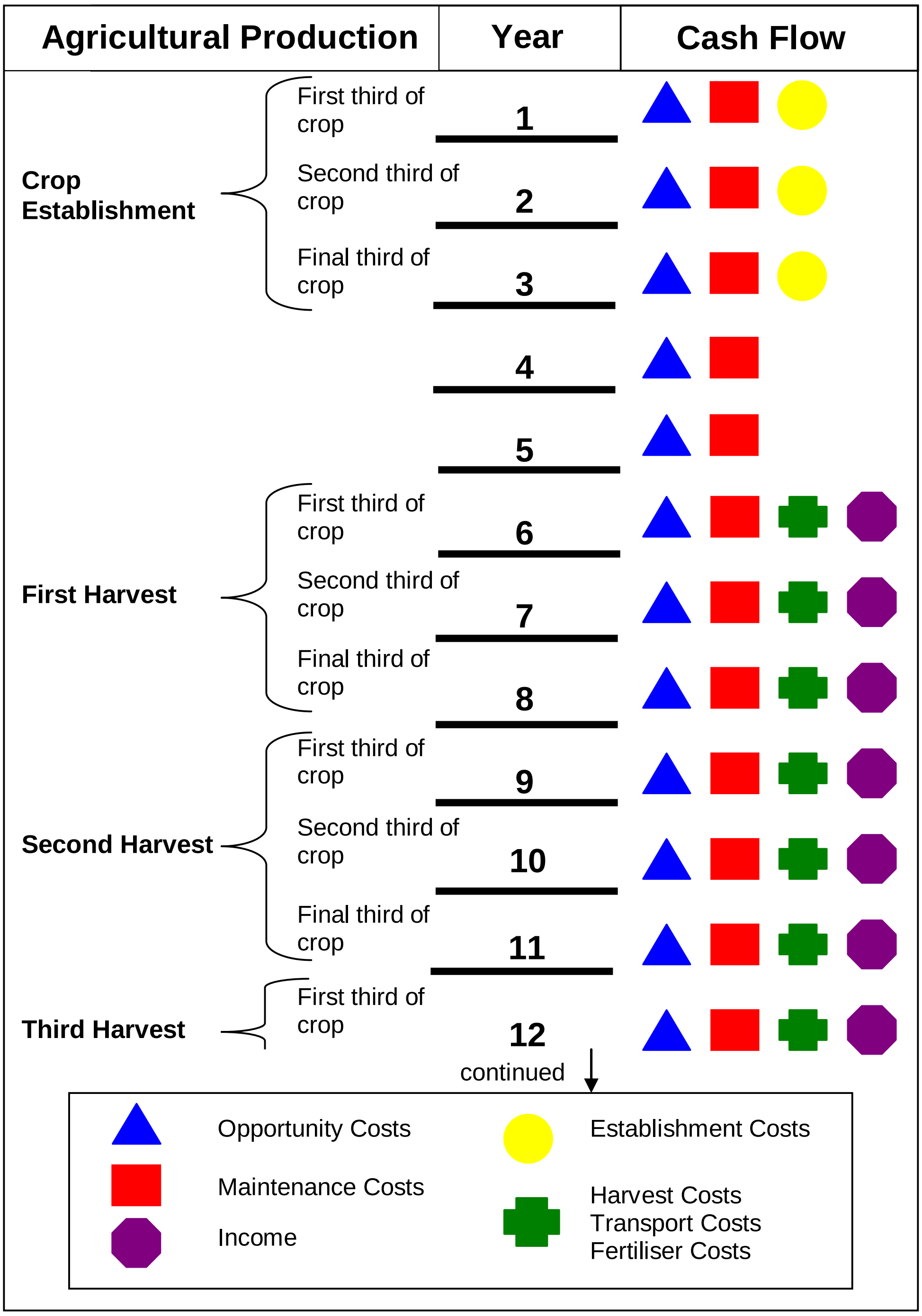

Figure 33 – Agricultural production schedule and cash flow for *Eucalyptus oleosa* grown for biomass.

Returns to the farmer are factory gate prices. These include transport costs based on the distance to the ITP plant and the quality of the roads required for travel. The location selected for establishment of the ITP is Kingston-on-Murray because there is a good selection of available land nearby. The plant is located in the heart of the highest salt-contributing land to facilitate the greatest public NRM benefits of biomass.

Economic returns to biomass production depend on the production of the site and the price per tonne of biomass. The principal input is the GIS layer of green biomass productivity of *Eucalyptus oleosa* in m^3/ha/yr. Bennell *et al*. (2004) produced a suitable layer capturing the spatial distribution of productivity based on experimental growth rates of *E. oleosa*. Originally created at a resolution of 5km grid cells, this layer was downscaled using bilinear resampling to 254m grid cell resolution to match the other GIS data used in the MCDA (Figure 34).

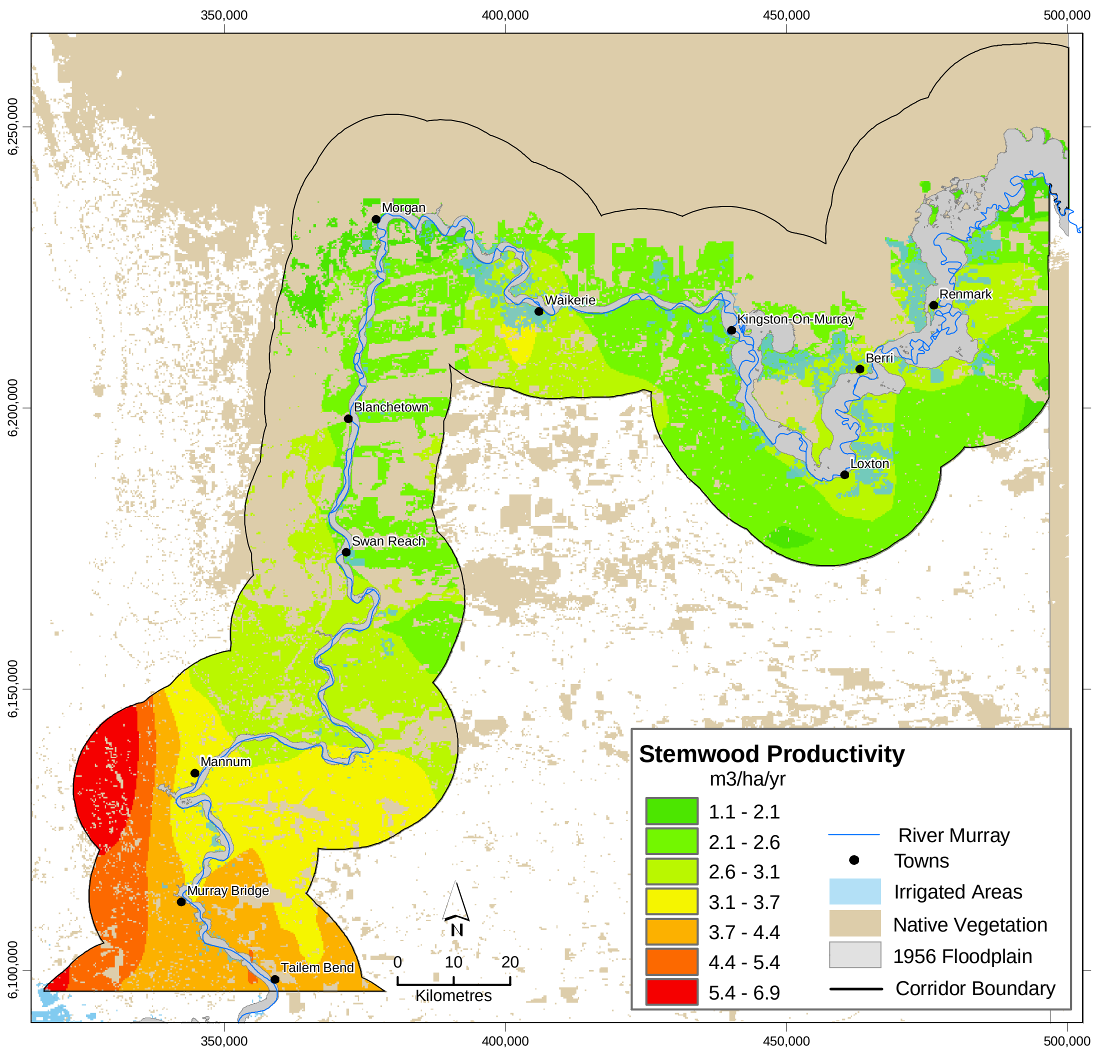

Figure 34 – Stemwood productivity of *Eucalyptus oleosa* in the Corridor downscaled from Bennell *et al*. (2004).

To calculate the revenue from biomass (R_t) at harvest at year (t) for each grid cell (k) we first calculate the production (P_t) as a layer with values for green tonnes of biomass calculated for each grid cell. To do this we multiply the stemwood volume productivity at harvest (s) of each cell (Figure 34) by the cell area (a) and the time in years since last harvest (m_t). A coppicing productivity multiplier (φ_t) is then applied which attempts to capture the increased productivity of the species after coppicing compared with establishment productivity rates. A stemwood fraction conversion factor (θ_t) is also applied which converts the stemwood volumes into total tonnes of green biomass (wood, twigs, leaves inclusive). This is all divided by a harvest schedule staggering component (g). In this case we use g = 1/3 because we are harvesting a third of the area each year.

$$P_t = 0 \; for \; t < 6$$

$$P_t = s.a.m_t \varphi_t .\theta_t .g \quad for \; t < 6$$

Where:

P_t = production (green tonnes of biomass)
s = stemwood volume productivity (m^3/ha/yr)
a = cell area (6.4516 ha)
m_t = time since last harvest (years)
φ_t = coppicing productivity multiplier (green tonnes per m^3)
θ_t = stemwood fraction conversion factor (scalar)
g = harvest schedule staggering component (g = 1/3)
t = year

For t >=6 and t <= 8
$\varphi_t = 1$
$\theta_t = 1.9074$
$m_t = 6$

For t > 8
$\varphi_t = 1.5$
$\theta_t = 1.7521$
$m_t = 3$

Finally, the revenue in dollars for each cell is calculated as a layer by multiplying the production in green tonnes of biomass of each grid cell by the factory gate price per green tonne in dollars (p). In the Most Likely Scenario we use a factory gate price of $30 per green tonne. Ward and Trengove (2004) found that the factory gate price of $47 per green tonne is the highest price for biomass that could be paid to farmers that still returns an internal rate of return to the ITP plant >= 15% (the sensitivity analysis also addresses factory gate price):

$$R_t = P_t.p$$

All costs are calculated as layers with values in dollars for each grid cell. Significant establishment costs are incurred from planting one third of the biomass crop at the beginning of years 1, 2 and 3 such that:

$$EC_t = ec.a.g \quad for \; t >= 1, t <= 3$$

$$EC_t = 0 \quad for \; t > 3$$

Where:

EC_t = Total establishment costs for year t ($)
ec = Establishment costs ($/ha)

Maintenance costs are incurred every year (but only occur for the total area of crop after year 3 due to staggered plantings) and are calculated as:

$$MC_t = mc.a.t.g \quad for \; t >= 1, t <= 3$$

$$MC_t = mc.a \quad for \; t > 3$$

Where:

MC_t = Total maintenance costs for year t ($)
mc = Maintenance costs ($/ha)

Harvest costs occur first at year 6 and then every year after that for one third of the total crop area harvested each year:

$$HC_t = P_t.hc \quad for\ all\ t$$

Where:
HC_t = Total harvest costs for year t ($)
hc = Harvest costs ($ per green tonne of biomass)

Fertiliser costs follow harvest and are calculated as:

$$FC_t = 0 \quad for\ t < 6$$

$$FC_t = fc.a.g \quad for\ t >= 6$$

Where:
FC_t = Total fertiliser costs for year t ($)
fc = Fertiliser costs ($/ha)

Opportunity costs are also incurred each year as the growing of biomass is considered to require the cessation of all prior agricultural land uses. On the local scale however, biomass may be integrated into agriculture and grown in strips to complement existing practices (e.g. provide wind breaks for livestock or lower water tables for reducing salinity effects on cropping). Opportunity costs are calculated for each cell by multiplying the opportunity costs per hectare (Figure 32) by the cell area:

$$OC_t = oc.a \quad for\ all\ t$$

Where:
OC_t = Total opportunity costs for year t ($)
oc = Opportunity costs ($/ha, see Figure 32)

Transport costs involve the costs incurred from trucking green biomass from each grid cell to the proposed ITP plant located at Kingston-on-Murray along the existing road system. Transport costs were calculated as a layer for the entire SA MDB INRM region using a *costdistance* function in a GIS. To construct this layer a cost multiplier layer was created using a variety of data sources to characterise the relative cost of traversing cells of different surfaces. The South Australian roads database (PlanningSA) was used to identify sealed and unsealed roads. Areas of irrigated and dryland agriculture, flood plain and remnant vegetation were also identified. A cost multiplier of 1 is used when travelling on sealed roads. The cost multipliers for different travel surfaces are summarised in Table 19. Transportation costs are lowest along sealed roads, slightly higher along unsealed roads and higher again over open paddocks. Transport is permitted across native vegetation and irrigated areas but the cost multiplier is high and so traversal of these surfaces is not favoured in the costdistance analysis. No travel across the flood plain is permitted unless it is along a road. The cost multiplier layer is multiplied by a transport price (*tp*) to calculate for each grid cell the total cost in dollars per tonne per kilometre ($/t/km) for traversing the cell and this layer is used as input into costdistance analysis.

Surface	Cost Multiplier
Sealed roads	1
Unsealed roads	1.2
Open paddock	1.4
Irrigated area or native vegetation	3
Flood plain	Not permitted

Table 19 – Multipliers for adjusting the costs of transport of biomass over different surfaces.

Costdistance analysis is a global function in raster GIS that is able to calculate the least expensive route from each cell to a target cell. Costdistance analysis combines the cost of traversal layer in $/t/km with distance measurement to the ITP plant at Kingston-on-Murray to calculate for each grid cell of the minimum cost of transport per green tonne of biomass to the ITP in dollars per tonne (*tc*) (Figure 35). This layer is then clipped to the Corridor study area.

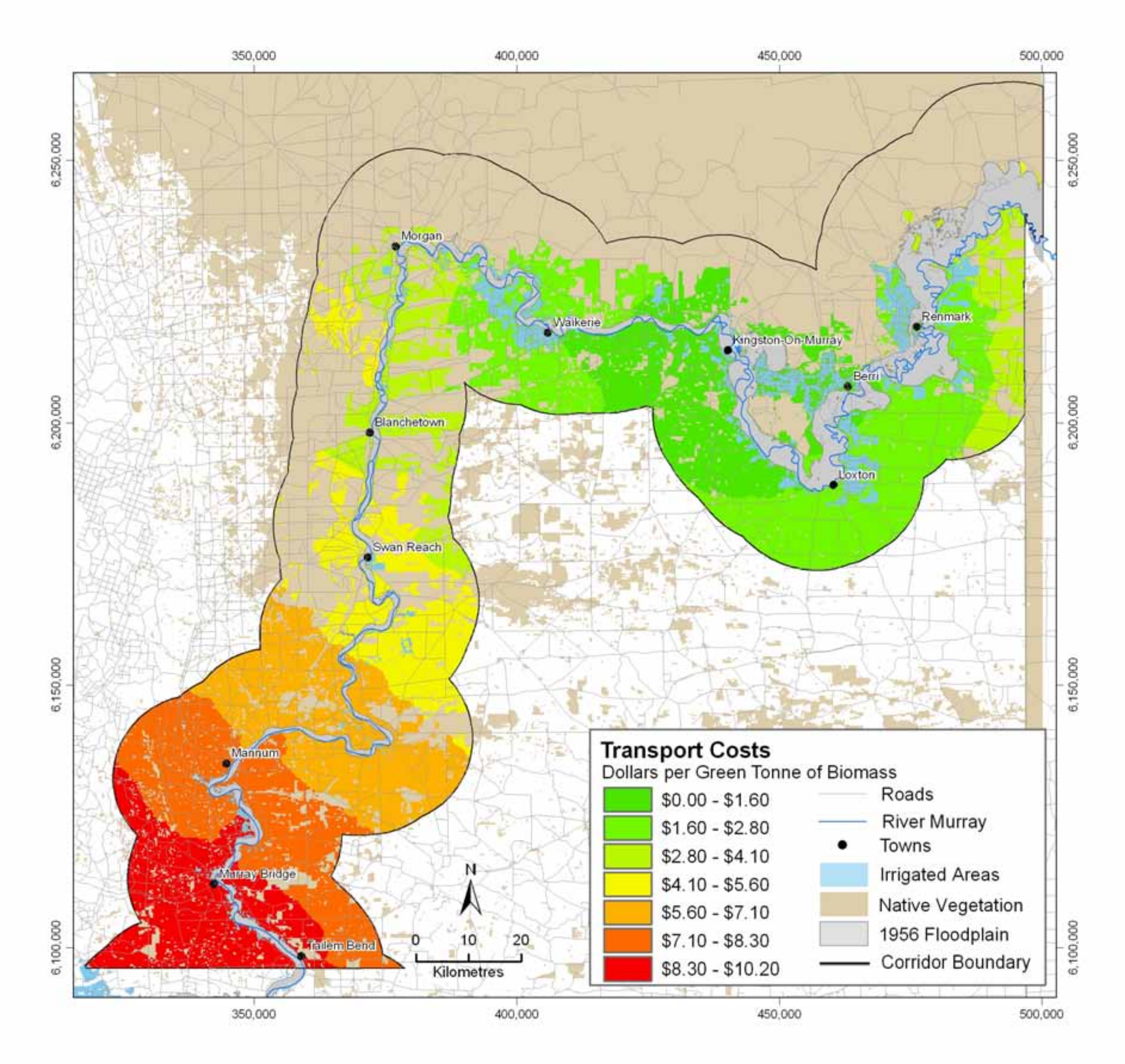

Figure 35 – Spatial distribution of transport costs ($/tonne) for the Corridor based on the price of $0.046/tonne/km.

To calculate the total transport cost layer we multiply this by the total production for each cell:

$$TC_t = P_t . tc \quad for\ all\ t$$

Where:

TC_t = Total transport costs for year *t* ($)

tc = Transport costs ($ per green tonne of biomass, see)

The six different types of costs involved in biomass production (establishment costs, maintenance costs, harvest costs, fertiliser costs, opportunity costs, and transport costs) can be used to calculate total biomass production costs in year t (c_t):

$$c_t = EC_t + MC_t + HC_t + FC_t + OC_t + TC_t$$

Three economic measures are used to assess the economic potential of biomass based on the above revenue and cost layers. Net Present Value is the total net returns to growing biomass (revenue – costs) discounted to present day dollars. Internal Rate of Return is the discount rate that results in the NPV of growing biomass equalling zero or, in other words, the percentage rate of revenue over costs. Equal Annual Equivalent is the equivalent annual payment required to return the NPV derived from growing biomass considering all of the irregular revenues and costs over time. Using these measures we can assess the profitability of growing biomass over current agricultural practices. By incorporating spatially varying data on production and cost parameters we can calculate the spatial distribution of the profitability of biomass for the Corridor as an attribute for input into MCDA.

More formally, Net Present Value (NPV) can be calculated as:

$$NPV = \sum_{t=1}^{n} \frac{(r_t - c_t)}{(1+i)^t}$$

Where:

i = interest (discount) rate
r_t = the revenue at year t
c_t = costs at year t
n = the number of years.

The Modified Internal Rate of Return assumes that all revenue will be reinvested as it comes in and is a function of the ratio of the present value of all costs (PV_c) to the future value of all returns (FV_r) from biomass. MIRR is calculated as:

$$MIRR = \sqrt[n]{\frac{FV_r}{PV_c}} - 1$$

where $$PV_c = \sum_{t=1}^{n} \frac{(c_t)}{(1+i)^t}$$

and $$FV_r = \sum_{t=1}^{n} (r_t)(1+i)^{n-t}$$

Using the NPV of biomass production, the Equal Annual Equivalent can be calculated as:

$$EAE = NPV \times \frac{i(1+i)^t}{(1+i)^t - 1}$$

Economic assessment of biomass in this study is necessarily highly parameterised. It involves specification of a range of values for model parameters that significantly affect the results of the analysis. There is some uncertainty surrounding all of the specified parameters. The economic assessment is conducted in two phases to cope with this uncertainty. First, the Most Likely Scenario performs a single analysis of the profitability of biomass production using the most likely parameter values. Second, a sensitivity analysis quantifies the effects of parameter uncertainty on the economic potential of biomass. Parameters and parameter ranges used in these analyses are specified in Table 20.

Model Parameter	Symbol	Units	Most Likely Value	Value Range
Establishment cost	*ec*	$/ha	740	400 – 1,200
Time frame	*n*	Years	100	20
Discount rate	*i*	%	7	0, 3, 6, 7, 9
Maintenance costs	*mc*	$/ha	10	5 - 15
Harvest cost	*hc*	$/t	12	7 - 20
Transport cost	*tc*	$/t/km	0.046	0.04 – 0.07
Fertiliser costs	*fc*	$/ha	40	30 - 50
Biomass price	*p*	$/t	30	15 - 45
Biomass productivity	P_t	t	See Figure 36	+/- 20%
Opportunity costs	OC_t	$	See Figure 32	+/- 30%

Table 20 – Model parameters and parameter ranges for economic analysis and sensitivity analysis of biomass (Note: t = green tonnes of biomass). The Most Likely Values are used in the Most Likely Scenario and the Value Ranges specify the range of values used in the sensitivity analysis.

The Most Likely Scenario involves a single calculation of the economic measures using the parameters in Table 20. The sensitivity analysis applies a Monte Carlo simulation on the economic measures by running the model 1,000 times for each of 5 different discount rates. For each iteration random parameter values are taken from the ranges specified in Table 20 including a random +/- 20% variation in both the biomass productivity and opportunity costs. Economic measures are recalculated over a time span of 20 years during each iteration. Hence, the sensitivity analysis tests the economic potential of biomass under the full range of possible parameter values. The Monte Carlo iteration was programmed within a GIS and took over 3 weeks to run on a 3GHz dual Xeon machine.

The first stage in the sensitivity analysis was to apply the 7% discount scenario and assess the effects of varying cost and revenue model parameters on biomass profitability based on the 1,000 model runs with random parameter values. The output is a series of Biomass supply curves that characterise the total tonnage produced from grid cells where biomass production is economically viable. It is assumed that landholders are rational beings and live in a world with perfect information. Hence, they will change their land use to biomass production if it is more profitable than current agricultural practices. The production of all cells with an NPV > 0 for each of the 1,000 iterations were summed to calculate the supply curves. These were plotted against the Factory Gate Price of biomass. One thousand NPV grids were calculated for the 0%, 3%, 6%, and 9% discount rates using model runs with random cost and revenue parameters. For each discount rate the mean and upper and lower 95% confidence interval was calculated for each grid cell based on the 1,000 iterations. This enables us to map the spatial distribution of the most likely NPV returns and also the lowest and highest NPV returns we could reasonably expect from biomass production for each grid cell. Finally, the risk of biomass production is calculated for each grid cell as the proportion of the 1,000 runs for which biomass production returns a NPV less than zero. This measure enables us to map the spatial distribution of the probability that, given the ranges of parameters tested in the sensitivity analysis, that biomass will be more profitable than current agricultural practices.

5.1.4.2 Results

5.1.4.2.1 Most Likely Scenario

The Most Likely Scenario facilitated the detailed assessment of the relative effect of different costs and prices on the viability of growing biomass in the Corridor compared with existing agriculture. Biomass productivity of *Eucalyptus oleosa* after the first harvest ranges from 24 –

115 green tonnes of biomass per year per grid cell (6.4516 ha) with an average of 51 tonnes per cell (Figure 36).

The value of establishment costs involved in a planting density of 1,000 plants per hectare is the same for all cells and was specified at $740/ha/yr. This equates to a present value of $4,468 for each grid cell. Maintenance costs are also specified on a per hectare basis and are the same for each grid cell. Specified in the Most Likely Scenario model at a nominal $10 per hectare, the total present value of maintenance costs is $860. Harvest costs vary spatially with biomass productivity. Specified at $12/tonne, the total present value of harvest costs of grid cells in the Corridor ranges between $3,400 and $16,300 (Figure 37). Fertiliser costs are based on area and so are the same for each cell. Specified in the Most Likely Model at $40/ha this equates to a present value of $935 for each cell. Opportunity costs vary spatially according to land use and climate. The present value of opportunity costs ranges from $771 - $19,600 per cell (Figure 38). Transport costs also vary spatially according to production and distance to the ITP plant at Kingston-on-Murray. Present value of transport costs ranges from $0 for cells adjacent to the proposed ITP at Kingston-on-Murray to $12,180 for grid cells far from the plant (Figure 39). Present value of total costs of biomass production for grid cells ranges from $11,600 to $46,200 over a time period of 100 years and at an discount rate of 7% (Figure 40).

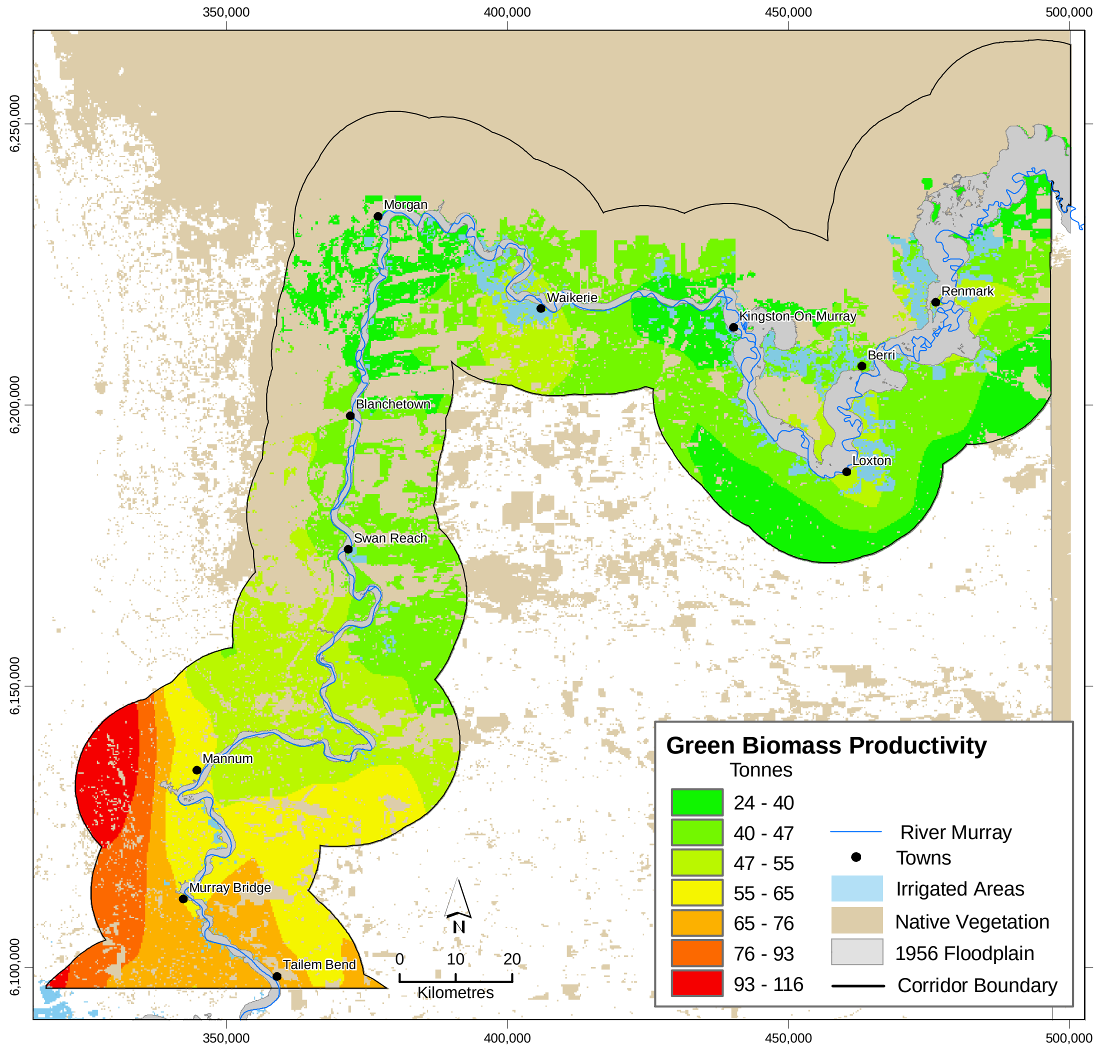

Figure 36 – Annual green biomass productivity (tonnes) for the Corridor from second and subsequent harvests.

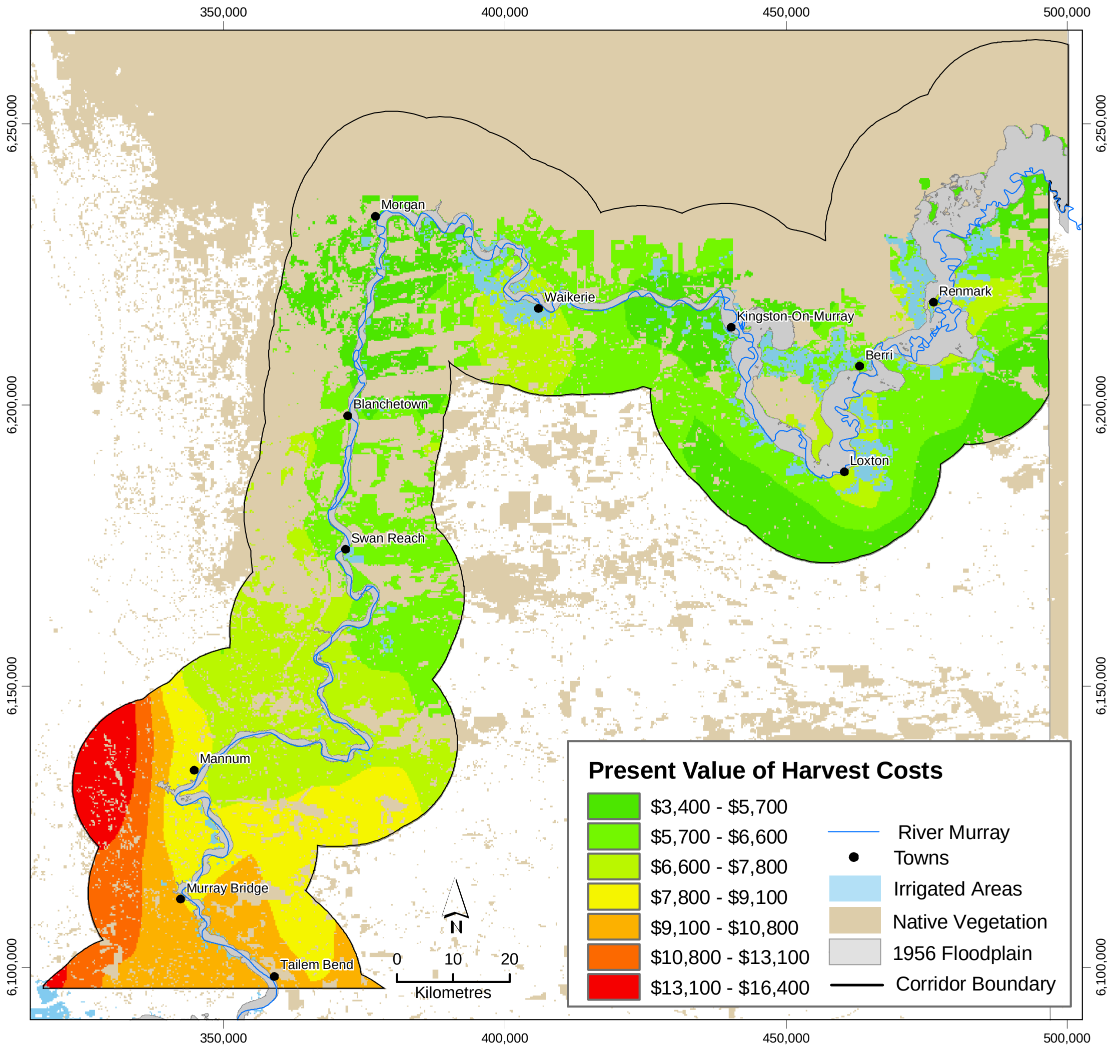

Figure 37 – Present value of harvest costs ($) for the Corridor based on the value of $12/ tonne and 7% discount rate calculated over 100 years.

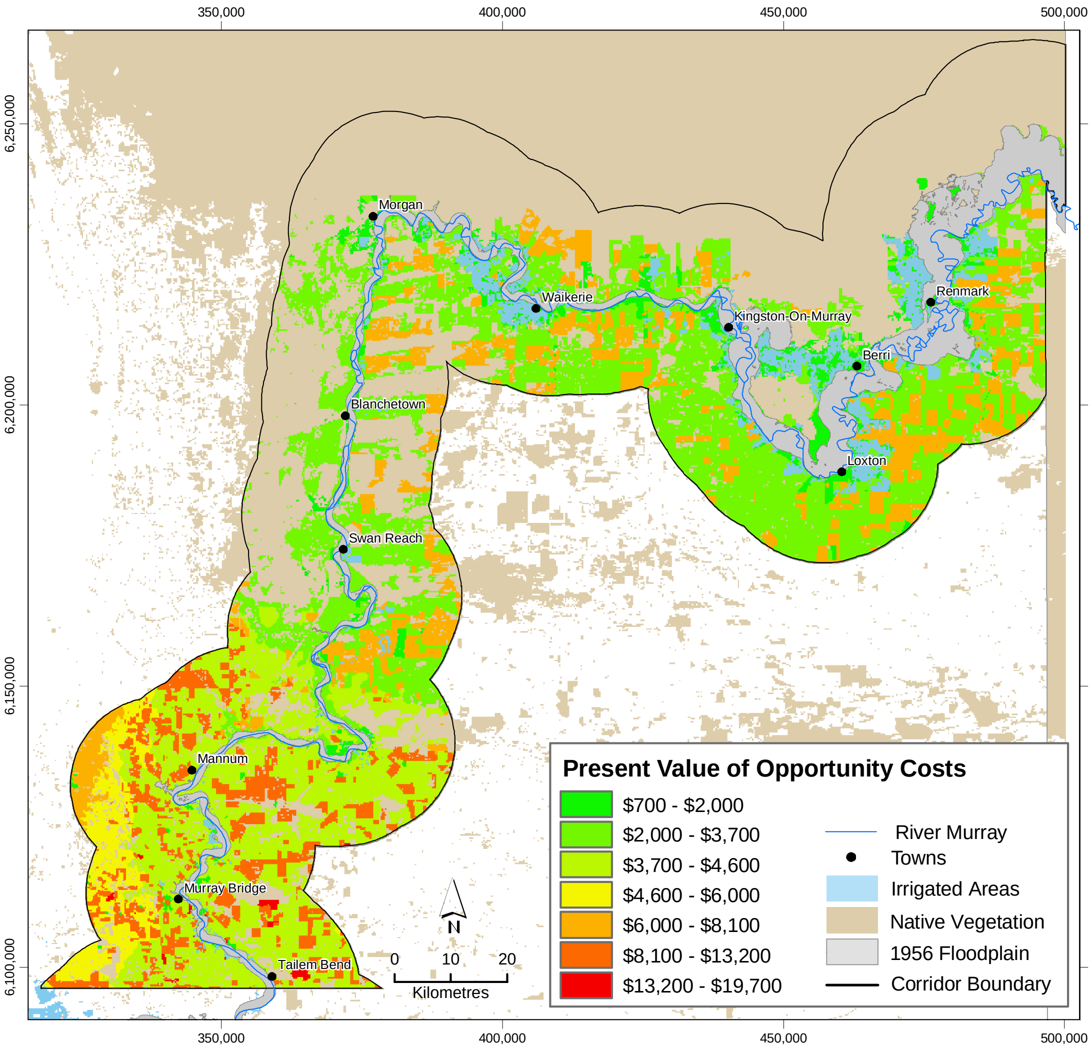

Figure 38 – Present value of opportunity costs ($) for the Corridor based on Figure 32 and a 7% discount rate calculated over 100 years.

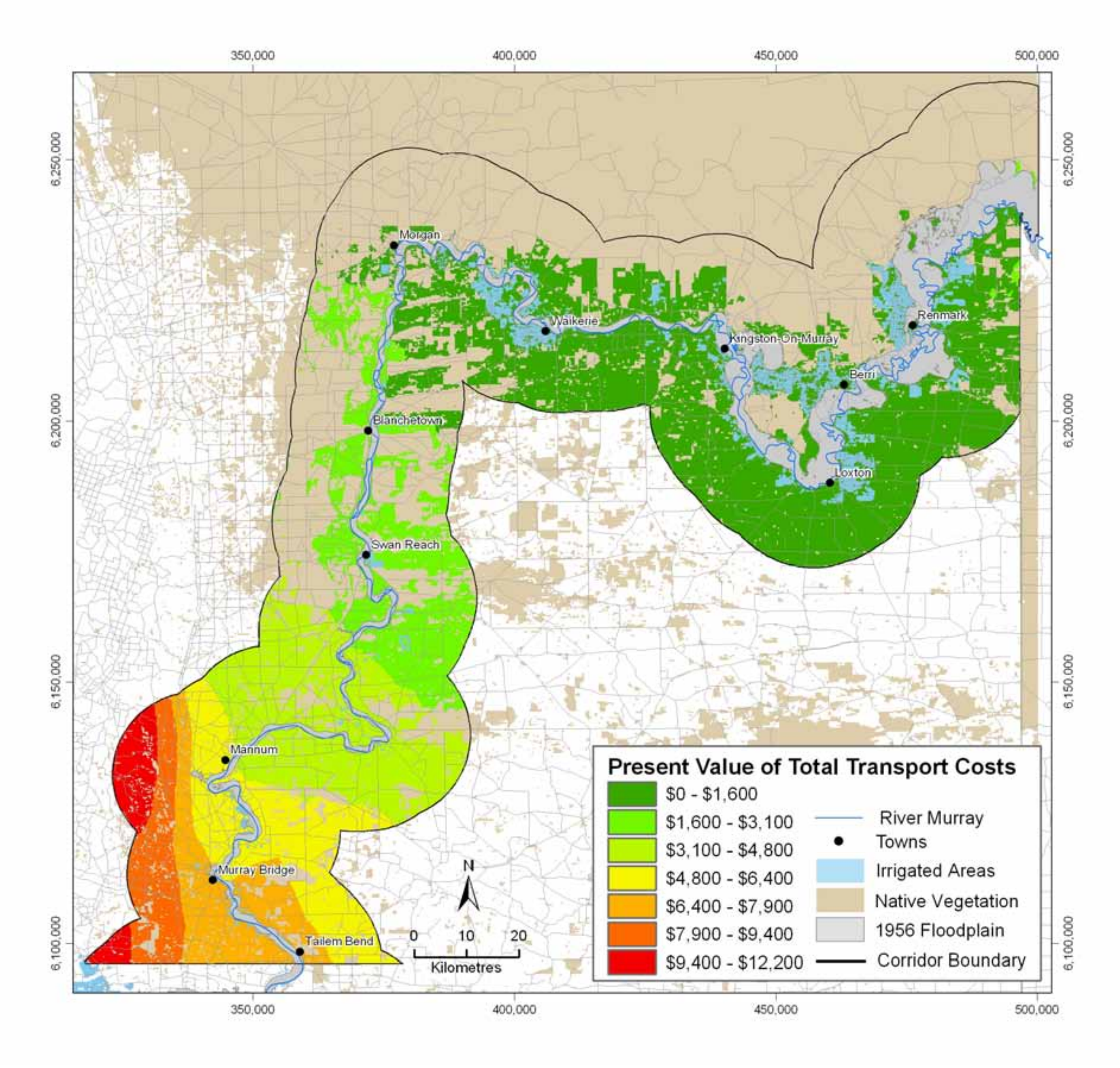

Figure 39 – Present value of total transport costs ($) for the Corridor based on a transport cost of $0.046/t/km and a 7% discount rate calculated over 100 years.

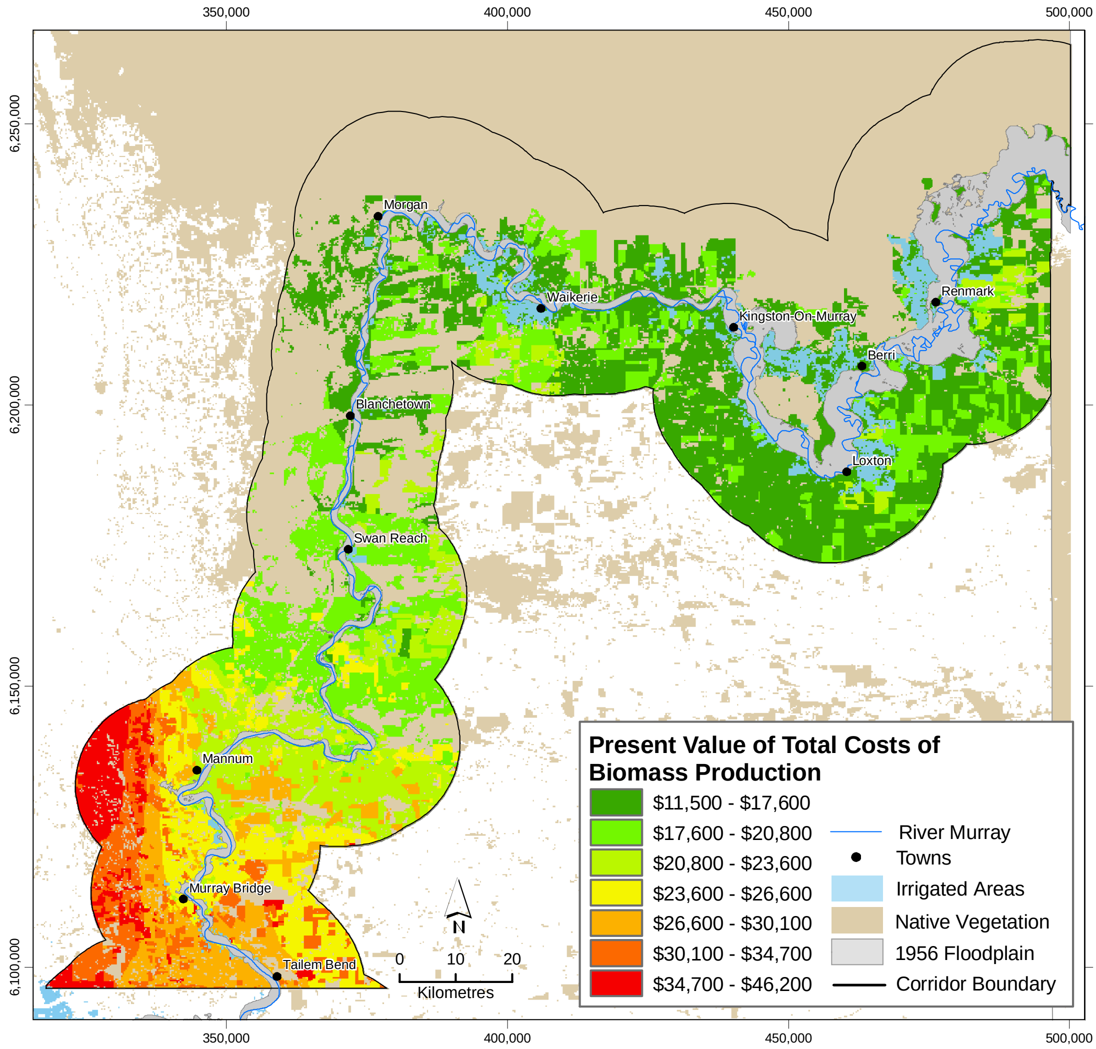

Figure 40 – Present value of total costs of biomass production ($) for the Corridor based on a 7% discount rate calculated over 100 years.

Present value of revenue from biomass production in the Most Likely Scenario ranges from $13,300 to $63,900 per grid cell (Figure 41). Assessment of economic measures in the Most Likely Scenario values reveals that biomass is more profitable than current agriculture in most parts of the Corridor. The total Net Present Value of biomass production ranges between $5,000 less, to $25,000 more, than returns from existing agriculture with an average NPV of $7,168 per cell (Figure 42). The Modified Internal Rate of Return ranges between 6.8% and 7.7% (Figure 43), which is acceptable, given that opportunity costs of existing agriculture are included in this analysis. Equal Annual Equivalent payments range from -$54 to $271 per year per grid cell or -$8.37/ha/yr to $42/ha/yr (Figure 44). We can consider biomass production to be potentially viable where the Net Present Value of production, which includes the opportunity costs of existing agriculture, is greater than zero. As a result, the total potentially viable area for biomass production under the Most Likely Scenario is 625,231 ha or 99.6% of the dryland area of the Corridor (Figure 45). The potential tonnage of green biomass supplied by the economically viable area (490 million tonnes) is considerably more than the required supply (100,000 tonnes).

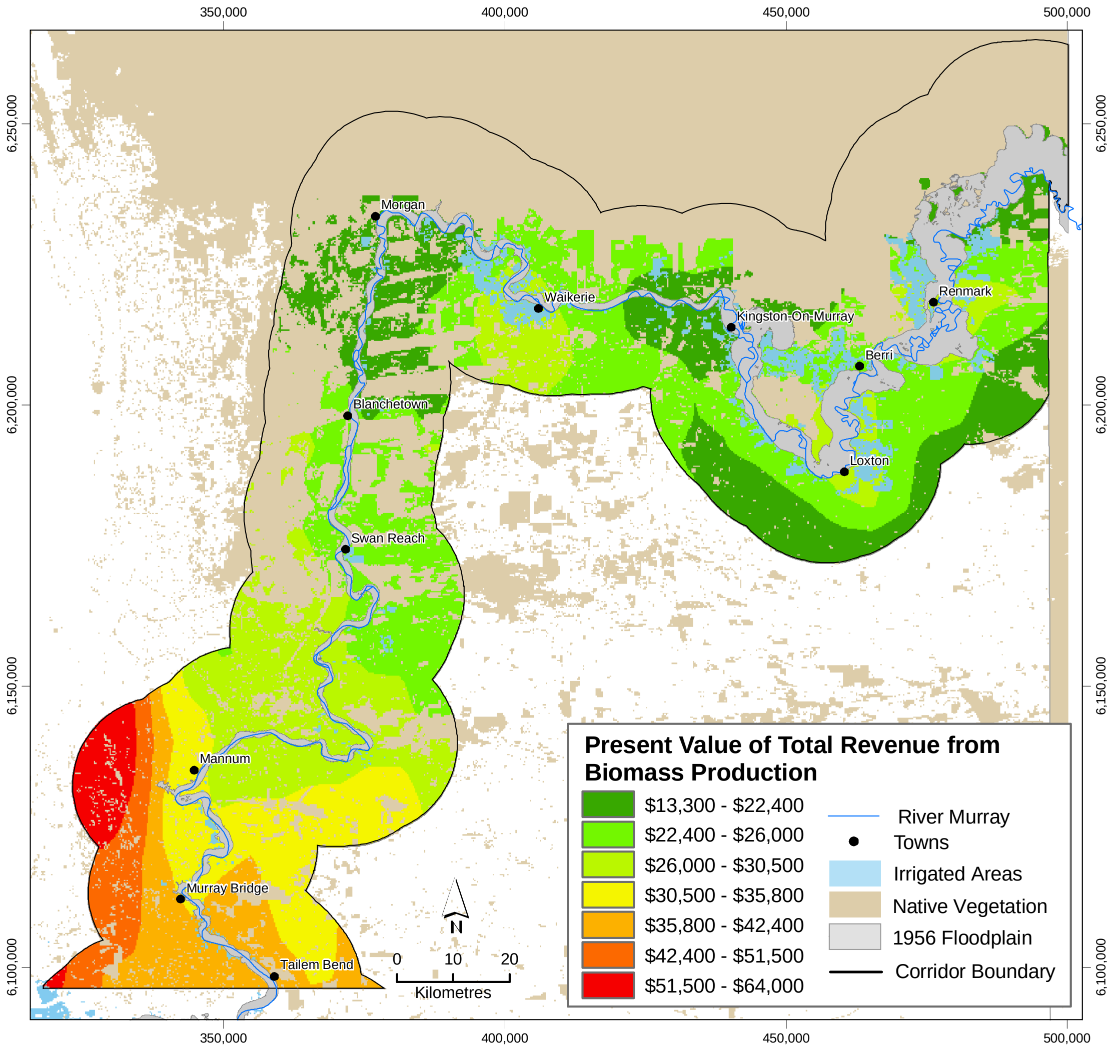

Figure 41 – Present value of total revenue from biomass production ($) per cell for the Corridor based on a 7% discount rate calculated over 100 years.

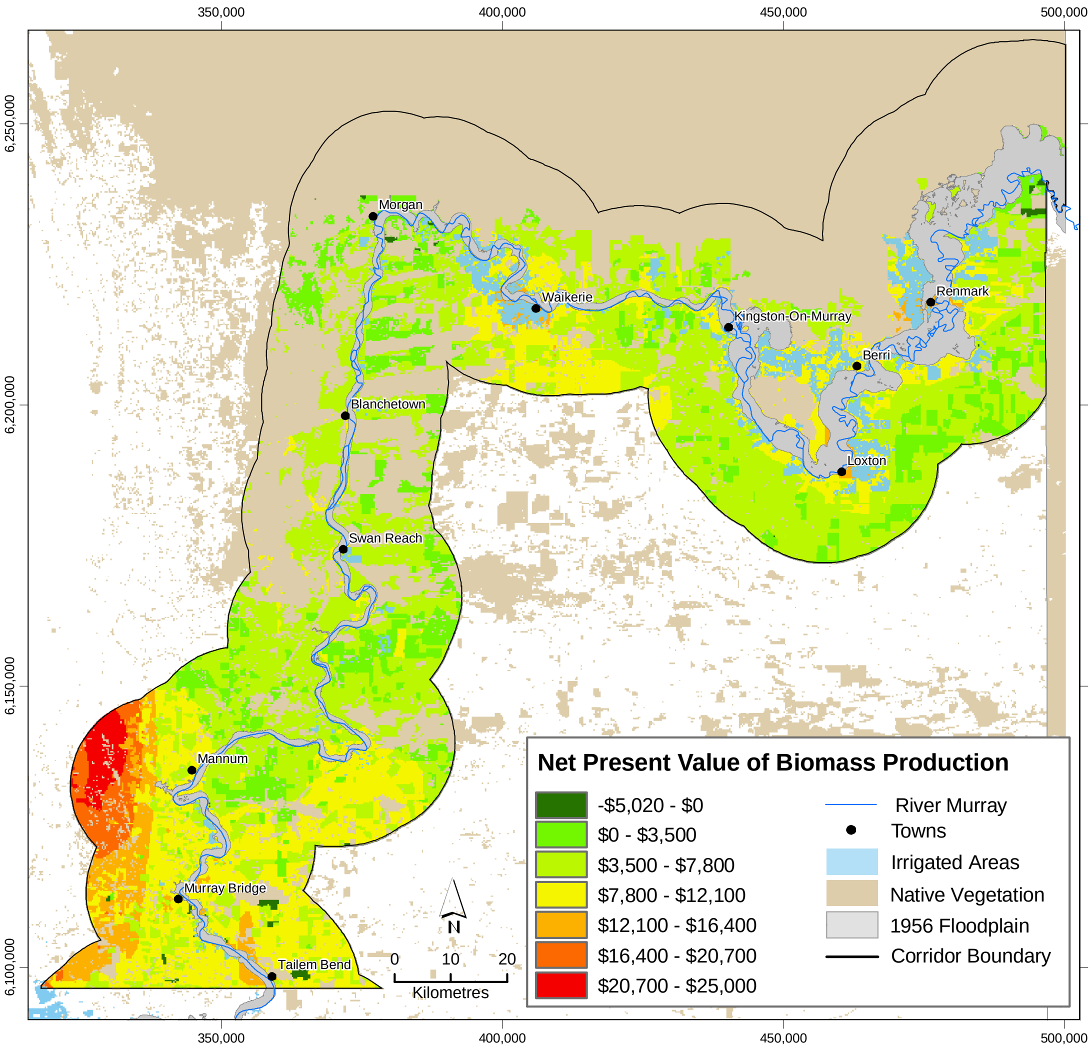

Figure 42 – Net present value of biomass production ($) per cell for the Corridor based on a 7% discount rate calculated over 100 years.

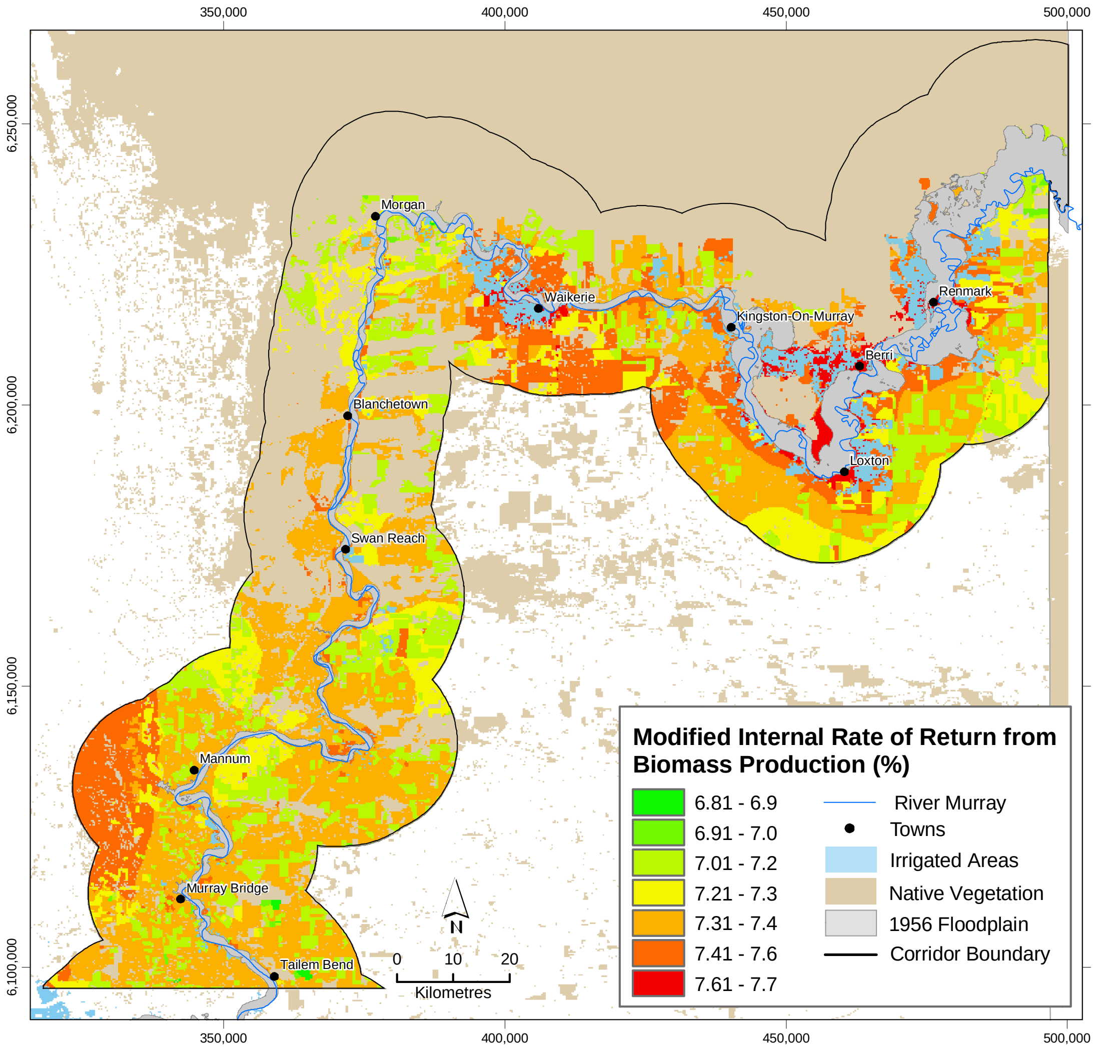

Figure 43 – Modified Internal Rate of Return from biomass production ($) for the Corridor based on a 7% discount rate calculated over 100 years.

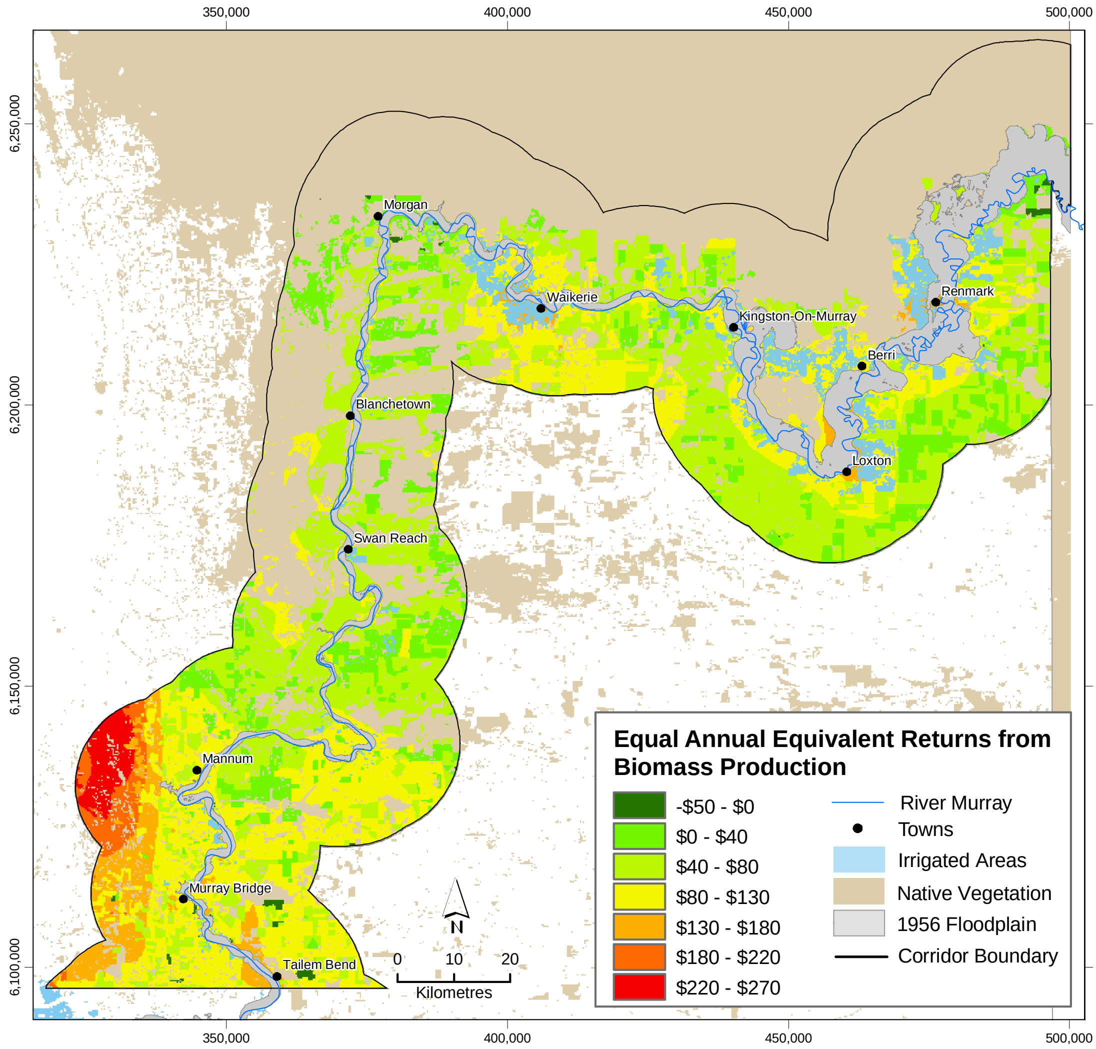

Figure 44 – Equal Annual Equivalent returns from biomass production ($) per cell for the Corridor based on a 7% discount rate calculated over 100 years.

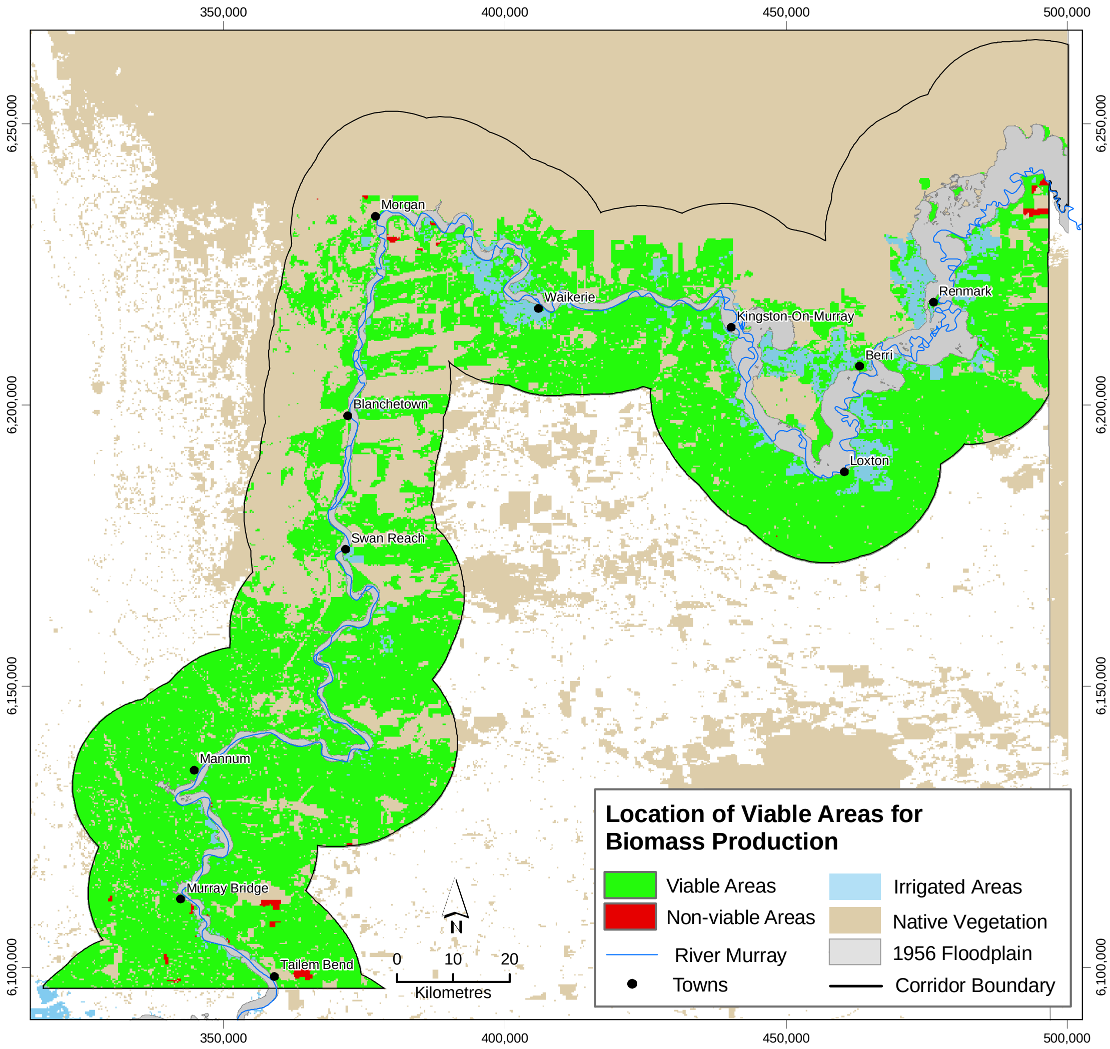

Figure 45 – Location of viable areas for biomass production in the Corridor based on a factory gate price of $30 per green tonne.

Ward and Trengove (2004) identify cash flow as an impediment to the development of a biomass industry. Four different sites were selected based on the results of the Most Likely Scenario for temporal cash flow analysis. The sites are:

1. A cereal cropping area near the Victorian Border;
2. A moderately productive site along the River Murray near Kingston-on-Murray with low transport costs and significant salinity benefits;
3. A low productivity site south of Loxton on cereal growing land, and;
4. A highly productive site in the higher rainfall area in the south-west of the Corridor but which also has high transport costs.

For each type of site there is a significant cash flow deficit in the first years of production and no sites experience a positive NPV until at least after year 7 (Figure 46). This is a significant obstacle to the large-scale uptake of biomass production by landholders. Although biomass is potentially more profitable than existing agriculture in many cases, policy is required that alleviates this cash flow problem for the first few years of crop establishment. Policy options include up front payments and/or low interest loans.

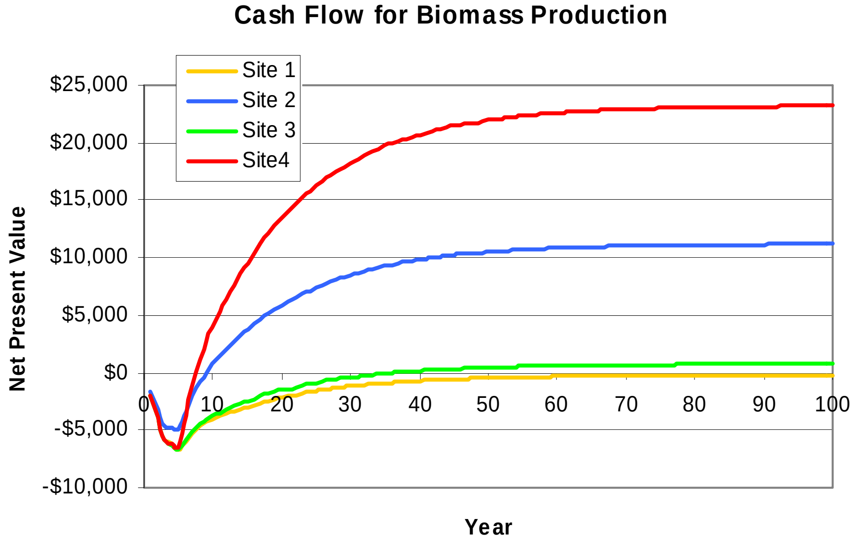

Figure 46 – Cash flow for biomass production of four sites with different economic and production characteristics at a discount rate of 7%.

The results present a comprehensive assessment of the regional economic viability of biomass production. The Net Present Value of biomass production is the most suitable economic measure for use as an attribute in MCDA. The Net Present Value map provides information on the most profitable locations for biomass production in the Corridor. The inclusion of this NPV in MCDA can be used in the objective function under the assumption that biomass can be produced in the most profitable locations. The more profitable the production the less the government subsidies required to offset costs.

The production layer is also a useful attribute particularly for inclusion as a constraint. Typical 5 MW ITP plants require approximately 100,000 green tonnes of biomass per year for full production. Total production at selected sites should exceed 100,000 tonnes per year.

5.1.4.2.2 Sensitivity Analysis

Sensitivity analysis of the biomass modelling using Monte Carlo iteration and random perturbation of model parameters reveals that there is good economic potential for biomass production in the Corridor. Over 2.5 million tonnes of green biomass may be produced annually in the dryland areas of the Corridor. However, the viability of biomass production varies over space and according to the parameter values used in economic modelling. Biomass production is not viable in any part of the Corridor under all parameter choices. It is important to understand where the most viable areas are and what parameter variation affects their viability. Table 21 and Figure 47 present the mean and the upper and lower 95% confidence intervals for the Net Present Value at 0%, 3%, 6%, and 9% discount rates, These statistical maps have been calculated over 1,000 Monte Carlo iterations and demonstrate the average scenarios and the lower and higher limits between which 90% of economic returns from biomass production occur.

The analysis of the statistical mean and 95% confidence intervals calculated on the NPV from 1,000 iterations at different discount rates illustrate the uncertainty involved in assessment of biomass profitability. The -95% confidence interval maps show that no grid cells are profitable under all possible parameter values. The mean values suggest that on average many parts of the Corridor are viable for biomass production but some are not.

Looking at the +95% confidence interval, all areas are viable and some are considerably more profitable than existing agriculture (Figure 47). Therefore, there is no guarantee of the viability of biomass under all potential economic situations. This is the nature of agriculture in dry regions such as the Corridor and biomass is likely to be viable in many areas under typical cost and revenue situations. Landholders can use this kind of information to base their land use decisions according to their own level of risk aversion (see Section 0).

Discount	Statistic	NPV ($)	MIRR (%)	EAE
0%	-95%	-20,486	-2.70	-204.9
	Mean	6,284	0.77	62.8
	95%	33,055	4.24	330.6
3%	-95%	-16,106	-0.06	-167.8
	Mean	2,829	3.42	29.5
	95%	21,764	6.91	226.7
6%	-95%	-13,316	2.48	-179.9
	Mean	535	6.02	7.2
	95%	14,386	9.55	194.4
9%	-95%	-11,809	4.81	-200.5
	Mean	-739	8.62	-12.6
	95%	10,330	12.43	175.4

Table 21 – Mean grid cell values for each statistical grid (mean, -95% and +95% confidence intervals) for each economic measure (NPV, MIRR, EAE) calculated over 1,000 runs at each discount rate (0, 3, 6, 9%).

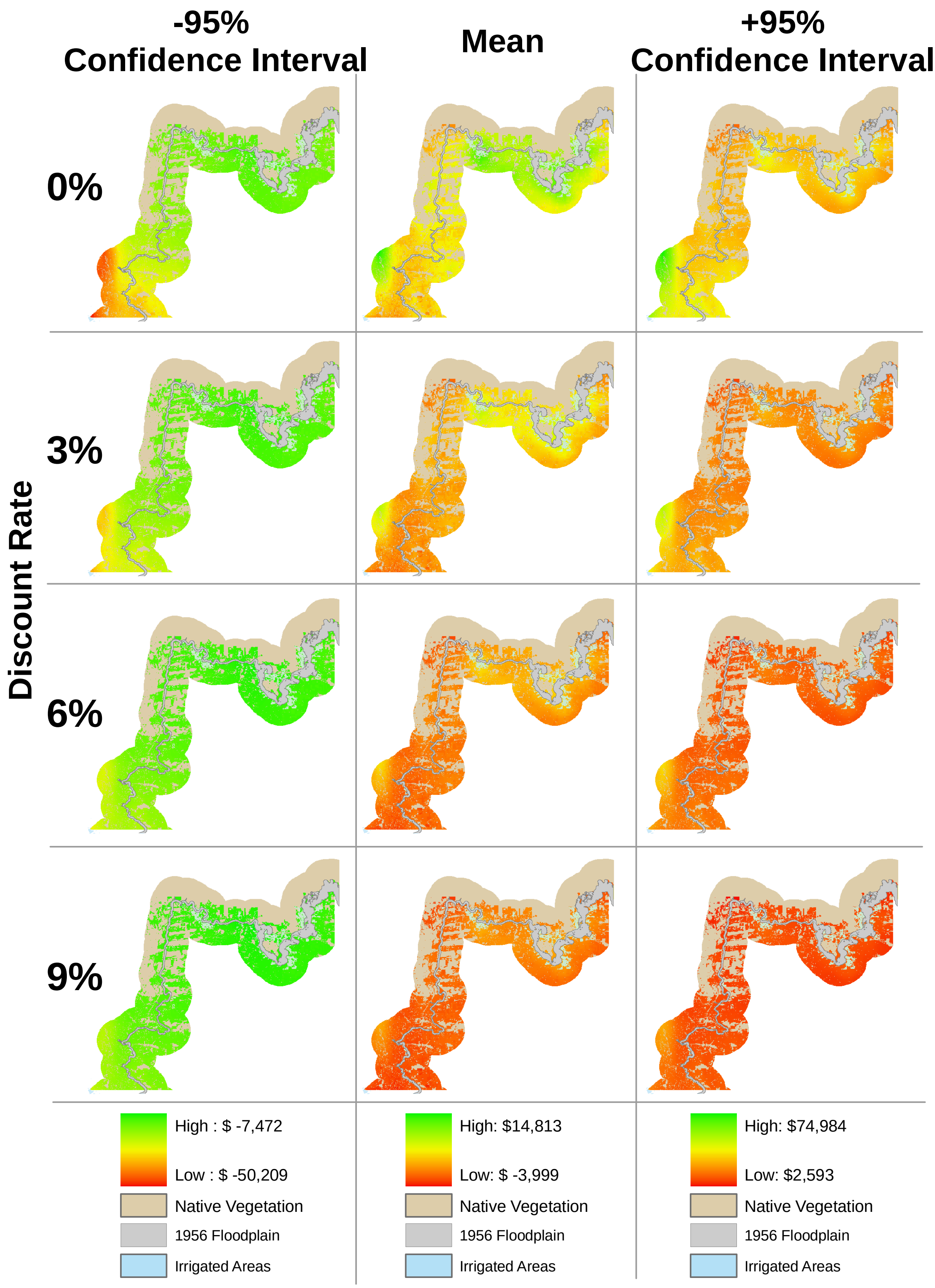

Figure 47 – Mean, lower and upper 95% confidence intervals of Net Present Value of biomass production summarised for 1,000 model runs at each discount rates of 0%, 3%, 6%, and 9%.

Variation in cost parameters tends to have only very slight effects on the mean net present value of grid cells. Variation in maintenance and fertiliser costs have no effect on mean NPV. Transport, establishment, harvest and opportunity cost parameter variation have a slight inverse relationship with mean net present value because the higher the costs, the lower the returns. In all cases there is significant variation about these trends (Figure 48).

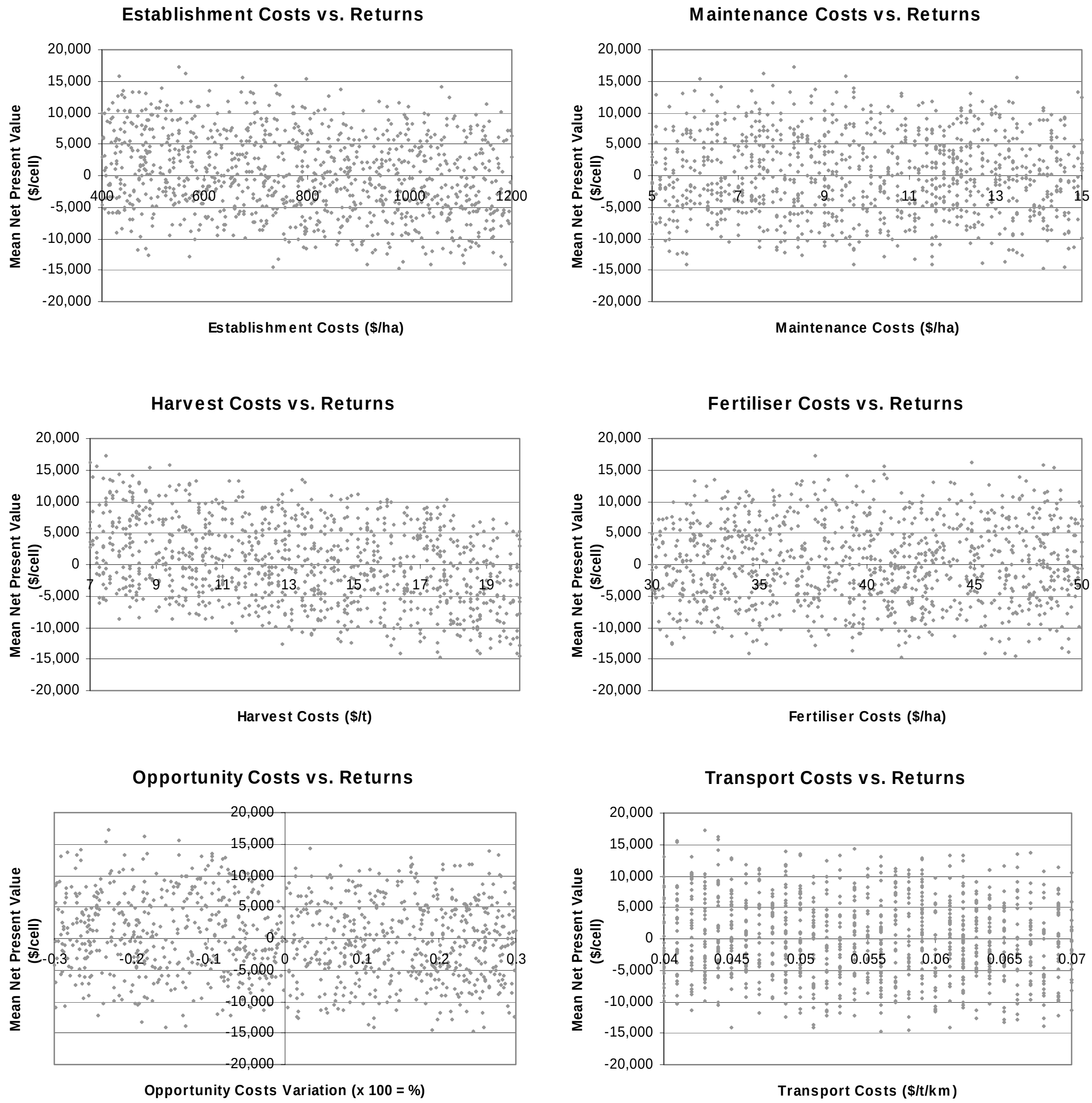

Figure 48 – Relationship between the mean Net Present Value of biomass production for all dryland non-vegetated grid cells and cost parameters calculated over 1,000 iterations, at a discount rate of 7%, and over a time horizon of 20 years.

Variation in productivity of biomass within +/- 20% of the empirical levels found by Hobbs (pers. comm. 2004) did not affect the mean NPV of grid cells in the Corridor. However, the factory gate price of biomass has a strong influence on the mean NPV returns from biomass production (Figure 49). Thus, the price of biomass is the single most important factor affecting the profitability of biomass production in the Corridor.

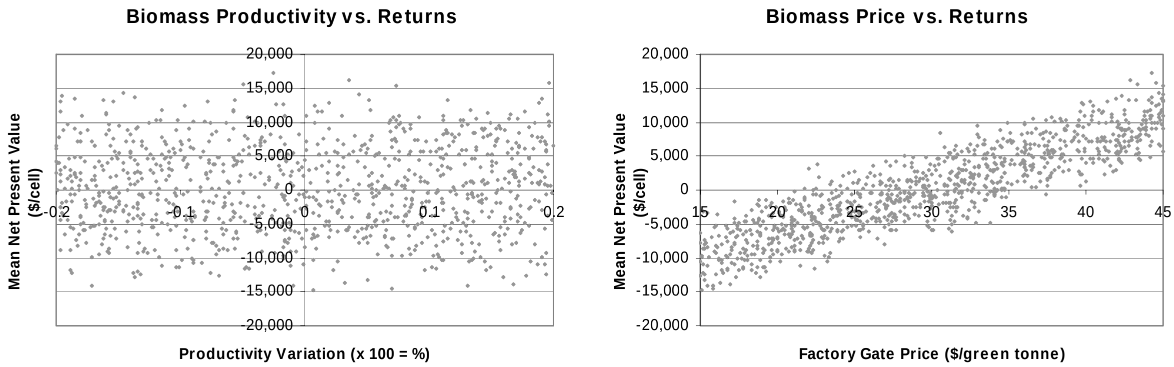

Figure 49 – Relationship between the mean Net Present Value of biomass production for all dryland non-vegetated grid cells and revenue parameters of productivity and price calculated over 1,000 iterations, at a discount rate of 7%, and over a time horizon of 20 years.

Taken conservatively at a 9% discount rate, the biomass supply curves (Figure 50) show that there is robust supply of >100,000 tonnes of biomass per year when the factory gate price of biomass exceeds $35 per green tonne. Supply is guaranteed at lower prices per tonnes for lower discount rates (Figure 50). This leaves a satisfactory level of flexibility in factory gate price between this price and the $47 per tonne maximum price found by Ward and Trengove (2004). Hence, a good starting price for biomass should be somewhere in the middle of this range to cater for uncertainty and other effects such as imperfect information and risk aversion of landholders.

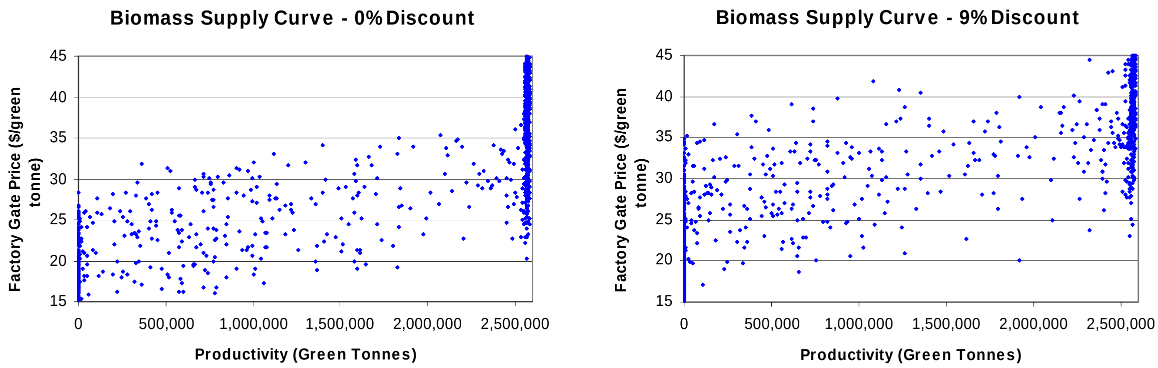

Figure 50 – Supply curves for biomass production at discount rates of 0% and 9%.

The effect of varying people's time preference is to moderate the extremes of economic returns. Assessment of the mean, and upper and lower 95% confidence interval grids calculated from the 1,000 models runs reveals that under a lower discount rate the high and low returns are more extreme. The other effect is that returns are generally lower at higher discount rates (Figure 47, Figure 51, Table 21).

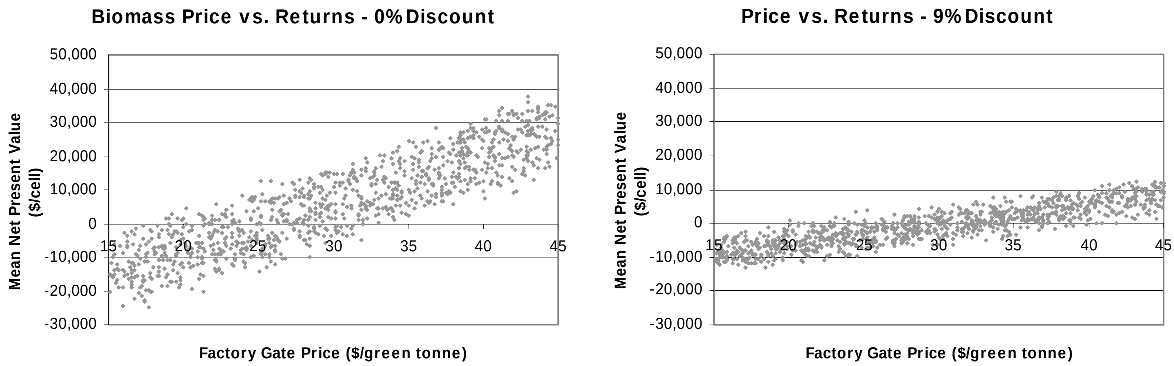

Figure 51 –Price per tonne vs. NPV of returns for biomass at discount rates of 0% and 9%.

Risk of biomass production is the proportion of the 1,000 sensitivity analysis model runs at 7% discount rate that the net returns from biomass production of each cell is greater than existing agriculture (NPV > $0). This measure captures the probability that each grid cell will be viable (i.e. have an NPV > 0) given the range of parameters tested in the sensitivity analysis. Risk probabilities range from a low of 30% to a high of 70% (Figure 52). In other words, at best, even the most viable cells have a negative NPV for 30% of the time given the range of cost and revenue values tested. This is a relatively high risk overall and is due to the low range of values for the factory gate price of biomass. As a result, this assessment is conservative.

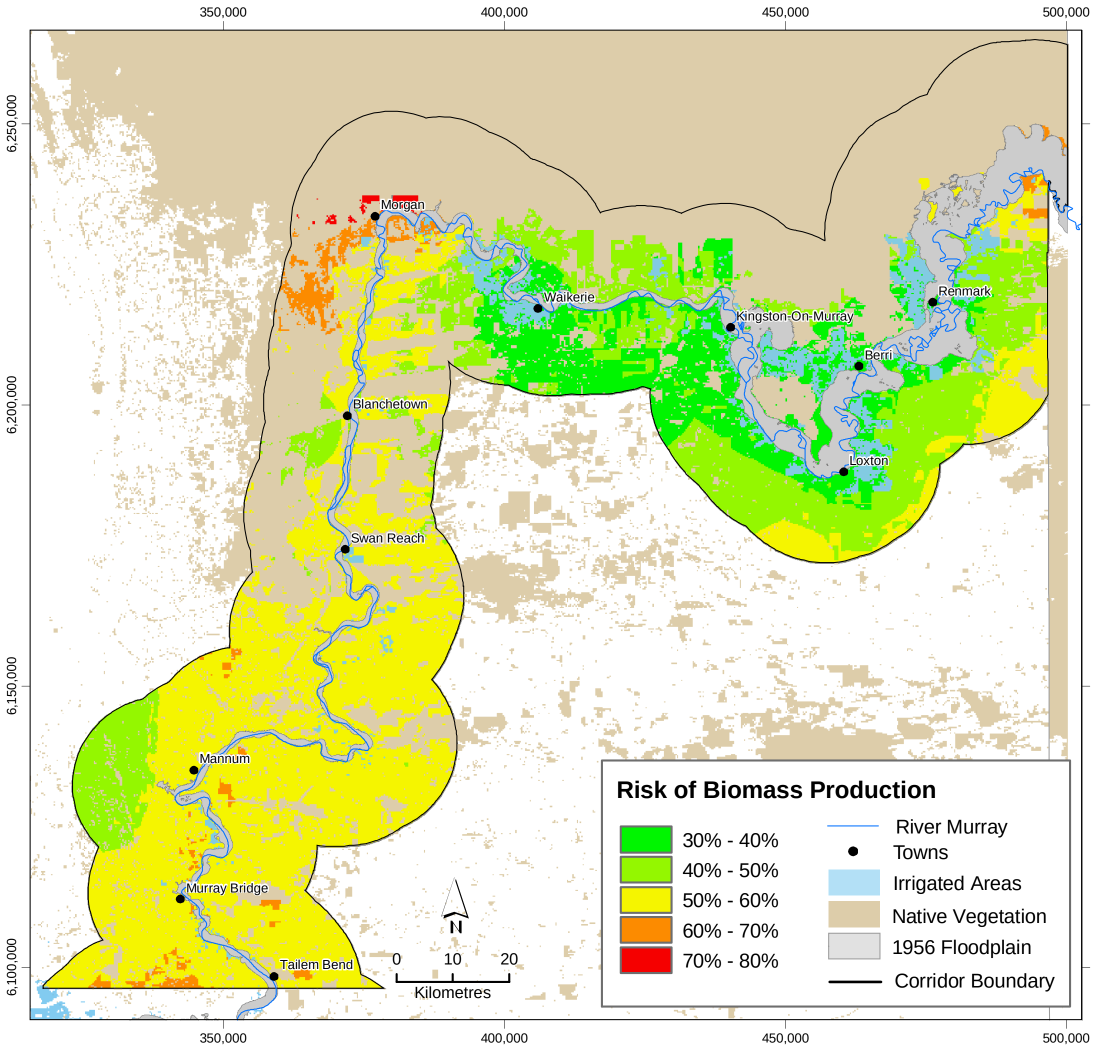

Figure 52 – Risk of non-viability of biomass production based on the range of parameter values tested and calculated at a discount rate of 7%. Green areas denote lower risk.

There is relatively low risk and good returns associated with biomass production around the stretch of high salinity benefit areas near the River Murray between Morgan and Renmark. Another interesting feature is the low risk – high return area in the eastern Mt. Lofty Ranges immediately west of Mannum. This high production area has relatively low opportunity costs as grazing is the primary agricultural activity. However, there may be other significant barriers to biomass production in this area including surface water and groundwater conservation issues and the loss of amenity value. This suggests that biomass production may have greater potential in the higher rainfall areas of South Australia. However, other higher value agroforestry products such as pulpwood production may be more economic than biomass industries in the higher rainfall areas. Bennell *et al*. 2004). More research is required to quantify the economic viability of biomass industries in these areas.

For the purposes of this study, three layers describing biomass productivity will be used as attribute layers in MCDA. Firstly, the net present value of biomass production from the Most Likely Scenario will be used to quantify the profitability (Figure 42). This layer will be used in the objective function with sites selected for biomass production that maximise profits. Secondly, the layer describing the total production in tonnes of green biomass from the second and subsequent harvests (Figure 36) will be used as the constraint that any biomass industry will need a supply of at least 100,000 tonnes per year. Last, the risk layer will be used to calculate the expected value so that sites can be selected for biomass production that offer the highest returns at the lowest risk.

Very recently, Hobbs and Bennell (2005) have released revised productivity estimates for mallee species in the Corridor based on their latest empirical results. New estimates of the productivity of *E. oleosa* are 1.5 – 2 times higher than those used in this study. Hence, the results of the economic assessment of biomass production in the Corridor is somewhat conservative. Based on these latest figures there is little doubt that biomass production in the Corridor is a viable exercise.

5.1.5 Wind Erosion

Wind erosion layers include both long-term eroding lands and wind erosion potential of soil landscape units as mapped by DWLBC (Figure 53). Long-term eroding areas will be included in the MCDA as a constraint that ensures that all vegetated long-term eroding areas must be managed and all cleared long term eroding areas must be revegetated either by local native species for biodiversity or by biomass. Wind erosion potential data will be included as a cost parameter in the objective function of the spatial optimisation. High wind erosion potential areas will form priorities for revegetation and vegetation management. Note that the long-term eroding areas and areas with high wind erosion potential may cost more to establish local native species and biomass crops as trees alone, without first establishing appropriate cover crops, may not adequately manage soils with high wind erosion potential. If not managed appropriately they may exacerbate the erosion problem because vegetation plantings with large holes (particularly on sand dunes) can tunnel wind. Local experience and expertise must be used to guide the on-ground implementation of appropriate NRM actions for these sensitive areas.

The total area of long-term eroding land in the Corridor is 312 ha and this area occurs in more than 100 locations in the Corridor. The long-term eroding areas information has been created at a fine scale and is almost incommensurate with the scale of other data layers used in this study. To counter this problem, long-term eroding area polygons are rasterised by classifying each cell that overlaps a polygon rather than the usual rasterisation process that results in many small polygons disappearing. This results in a conservative approach to the management of long term eroding land because the total area targeted for NRM actions to address erosion is substantially greater than the mapped long-term eroding areas and prioritises many neighbouring areas for NRM actions.

Wind erosion potential in the Corridor is mapped by DWLBC into 5 classes from high to low (Table 22) based on the clay content of the soil. For the purposes of this study, each class is given a cost score form 1 to 5 with 1 being high wind erosion potential. Thus, in the MCDA, high erosion potential cells will be prioritised for INRM actions. There is more than 7,200 ha mapped as high wind erosion potential in the Corridor which is considered to be unsuitable for cropping and a further 32,000 ha classed as moderately high which is only semi-arable (Table 22). Thus, wind erosion is a significant NRM issue in the Corridor.

Erosion potential is mapped for all cleared areas in the Corridor but not for all of the vegetated areas. There is a large unmapped area north of the river that represents the limit of soil landscape mapping in South Australia. Values are required for input into the MCDA and so all unclassified areas are given the value of the nearest valid cell. This process is a significant source of error in prioritising vegetation management and better solutions for dealing with unmapped areas should be developed in the future. The impact of this modelling artefact though is likely to be minimal.

Wind Erosion Potential	Cost Score	Area (ha)
High	1	7,258
Moderately High	2	32,767
Moderate	3	208,206
Moderately Low	4	437,276
Low	5	331,902

Table 22 – Wind erosion potential classification for use in MCDA. Note that the DWLBC Soil Mapping Classes are the inverse of this.

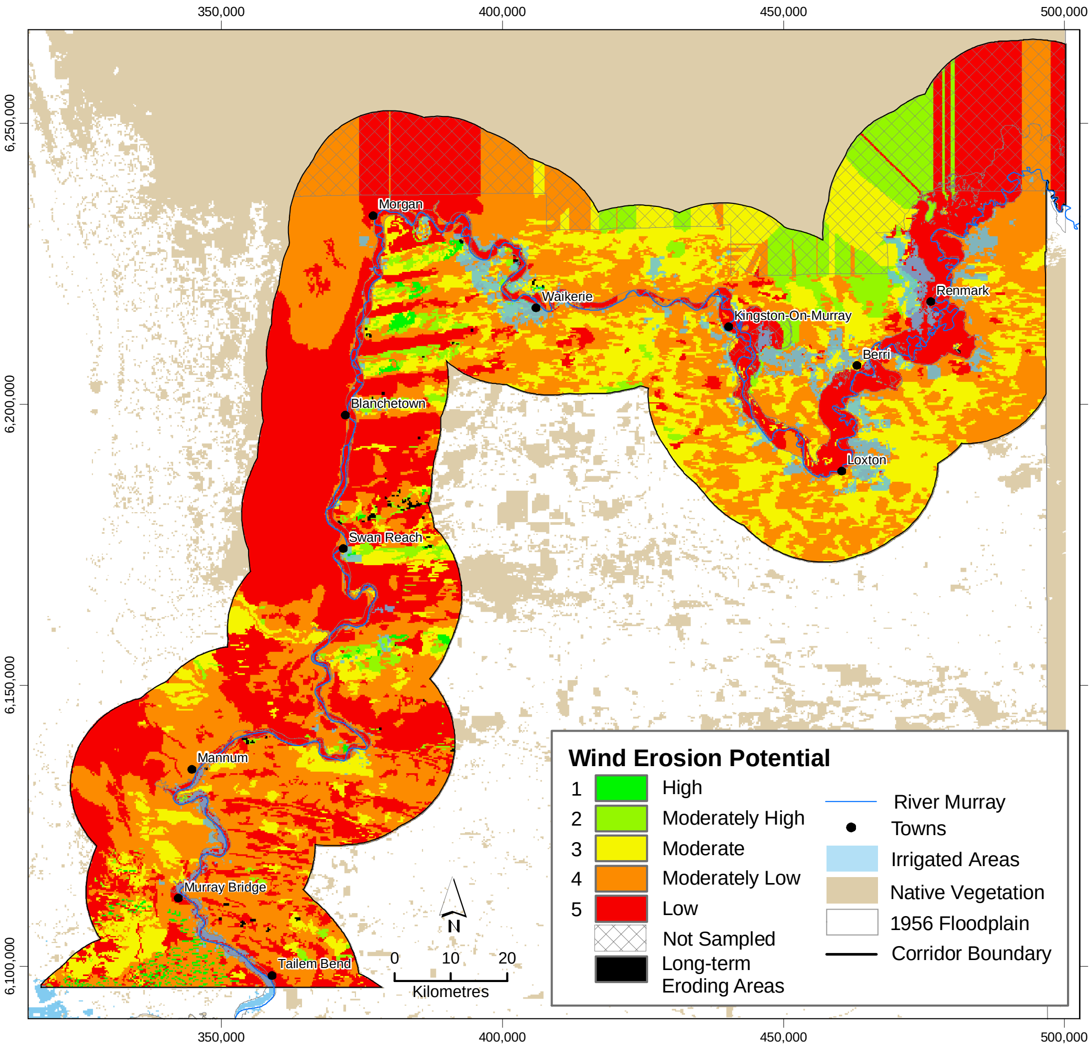

Figure 53 – Wind erosion potential and long term eroding areas in the Corridor. The cross-hatched area north of the River Murray represents the areas of unmapped wind erosion potential.

To summarise, this section has laid the groundwork for systematic regional planning for multiple objective NRM. We detailed the construction and modelling of a variety of attribute layers which capture the spatial distribution of geographic priorities for NRM actions for salinity, biodiversity, and wind erosion benefits. In this section we also describe the spatial distribution of biomass opportunities and the opportunity costs of agriculture. All of these attribute layers provide insights into NRM in the Corridor and are included in the MCDA in the process of systematic regional planning for multiple objective NRM. The rest of the MCDA

5.2. Decision Alternatives

The decision alternatives in the MCDA in this study are represented as grid cells. Each grid cell can either be selected for a certain NRM action (e.g. revegetation for biodiversity, vegetation management, or revegetation for biomass) or not selected for any action. The Corridor study area is tessellated into 188,655 grid cells, each covering an area of 6.4516 ha. For each NRM action, particular grid cells are masked out of the analysis according to their land tenure and protection status. Only privately-owned remnant vegetation cells can be targeted for vegetation management and only dryland cells (non-flood plain, non-irrigated, non-vegetated) can be targeted for revegetation for biomass and biodiversity. We constructed a series of land cover, land tenure, and conservation status layers to mask the appropriate grid cells out of the analysis.

The land cover layers include irrigated areas derived from the Crops2003 database created by DEH. Crops2003 identifies all land areas that were irrigated in 2003. Note that irrigated areas change regularly (Bryan and Marvanek 2004) and this information is a snapshot of the extent of irrigation in 2003. The flood plain is identified using the extent of the 1956 flood as mapped from aerial photography by DEH. Lastly, the vegetated areas were derived from spatial databases assembled from the DEH vegetation surveys of the Western Murray Flats, Southern Olary Plains, Mid North, Southern Mt. Lofty Ranges and Murray Mallee as described in Crossman *et al*. (2004). The databases were merged and rasterised to match the other data layers. The distribution of these land uses in the Corridor is presented in Figure 1.

Land tenure is derived from the Digital Cadastral Database (DCDB). Private land is derived by selecting land parcels identified as *freehold* and *crown lease* tenures from the DCDB. All other land is considered to be government owned public tenure (Figure 55).

We combined National Parks and Wildlife (NPWS) Reserves, Ramsar wetlands, Heritage Agreement Areas, and the Bookmark Biosphere Reserve to identify existing protected areas. National Parks and Wildlife Reserves include all gazetted parks and reserves declared under legislation (Bryan 2003). Heritage Agreement Areas are voluntary conservation agreements between the government and the landholder that protect remnant vegetation on private land. Under a Heritage Agreement the landholder undertakes to manage the land in a way conducive to nature conservation and the agreement is usually attached to the land title. Ramsar wetlands are also classified as protected although the actual level of protection of these globally important wetlands is low. The Bookmark Biosphere Reserve was declared under UNESCOs Man and the Biosphere Program and includes a diverse range of environments from semi-arid Mallee and rangeland to wetlands of international importance. Land uses in Bookmark are equally diverse, ranging from NPWS reserves to working sheep stations and wineries. The Bookmark Biosphere Reserve is assumed to be protected in this study. Datasets for the four types of protected areas were acquired from DEH and assembled into a protected areas layer by Crossman *et al*. (2004).

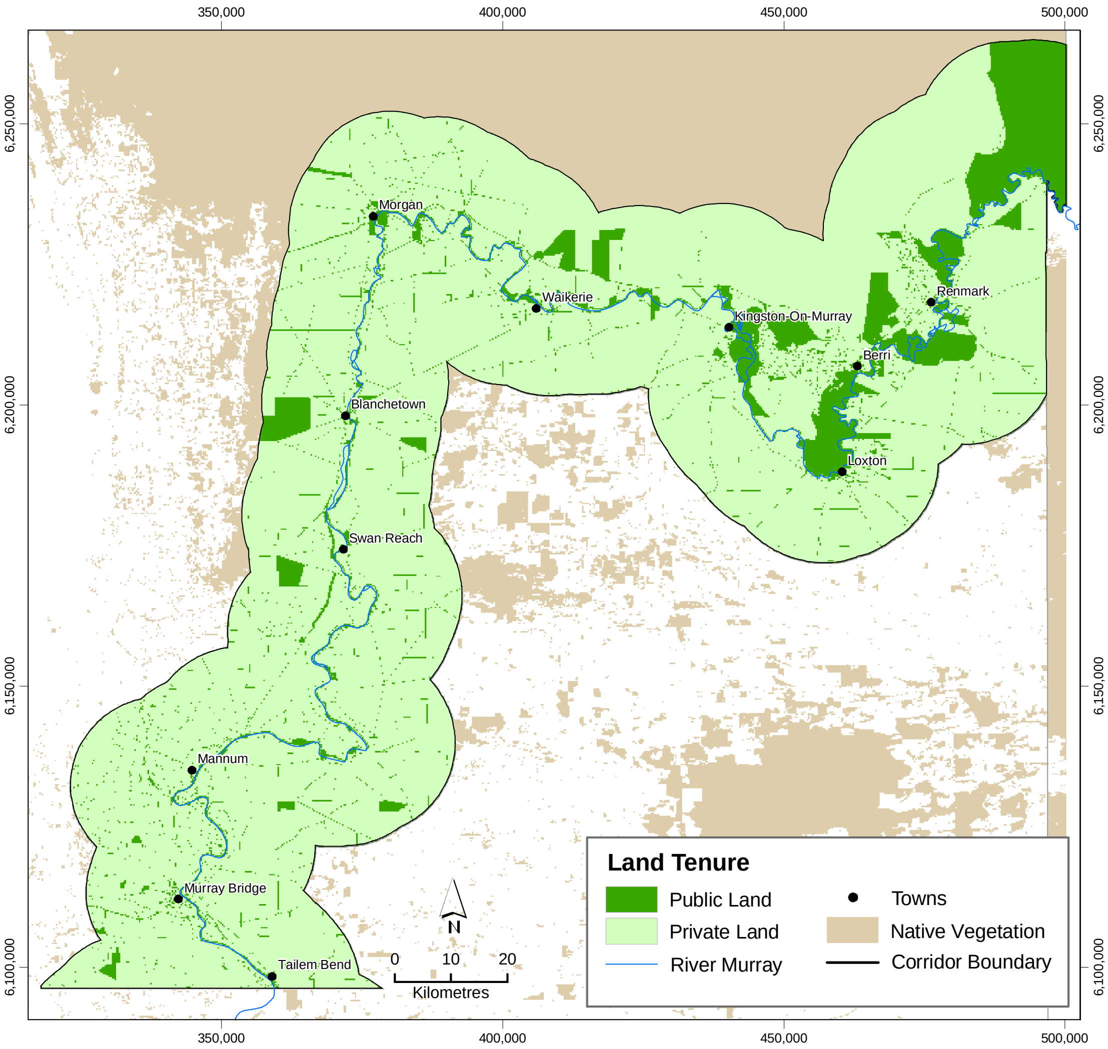

Figure 54 – Private and public land tenure.

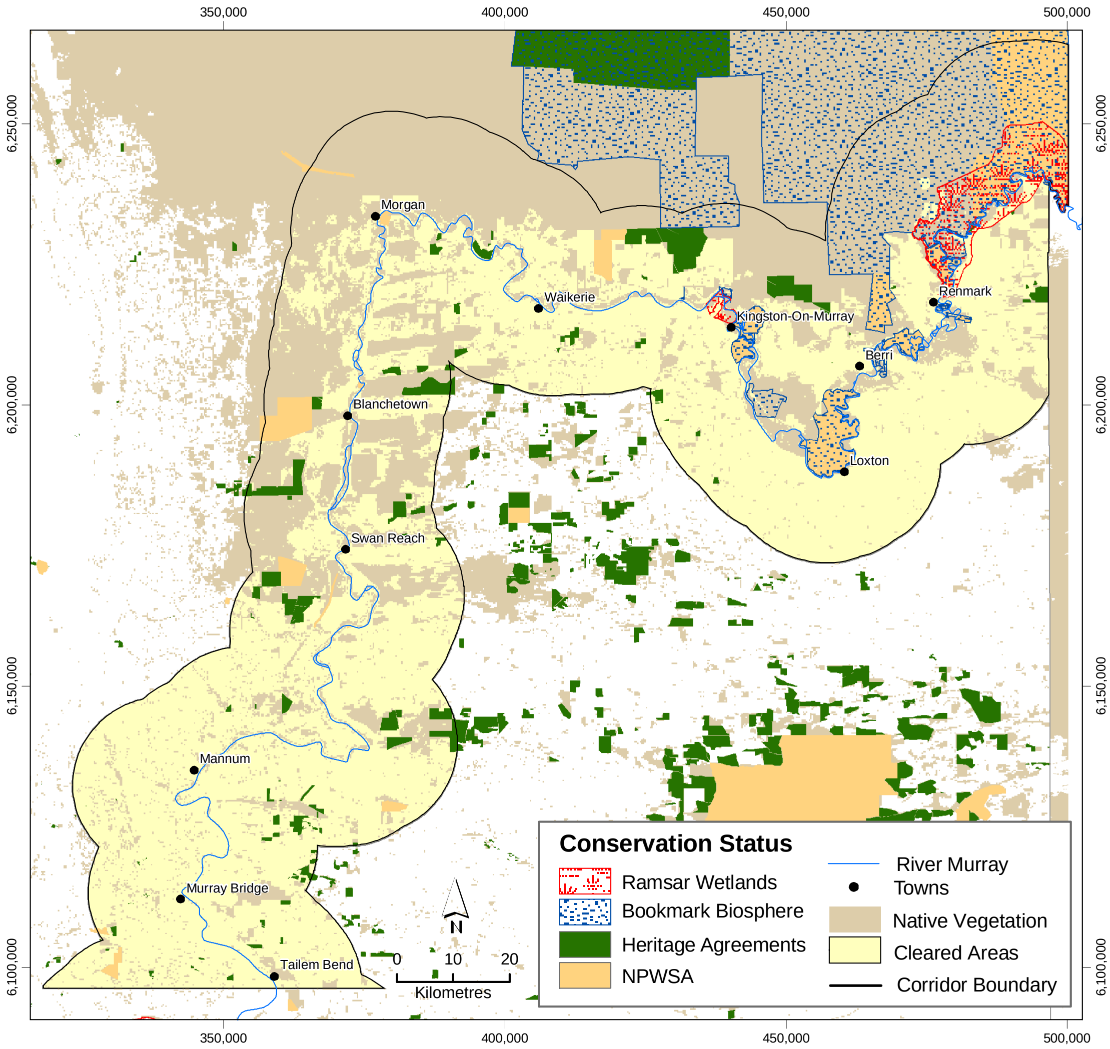

Figure 55 – Protected areas and conservation status.

5.3. Criterion Weights

In the spatial MCDA in this study, an objective function is used which is a function of the attribute layers. The objective function usually takes the form of either minimising costs or maximising benefits. Criterion weights may be applied to attributes in the objective function to increase the relative influence of individual attributes. Weights can be used to emphasise the influence of certain parameters considered important to the decision maker over other considered less important. There are several ways in which weights may be derived in MCDA (Jankowski 1995). We build in the ability to include weights in the decision process in spatial MCDA in this study. However, in our models all attributes are considered equivalent and are weighted accordingly. Attributes are generally rescaled using cost scores between 1 and 4 or 5 to facilitate numerical integration without bias.

5.4. Decision Rules

There are a variety of ways of integrating the disparate data layers for prioritising grid cells for NRM actions that most cost-effectively meet resource condition targets. The general class of problem is one of spatial optimisation. Spatial optimisation for landscape planning has taken the form of two classic operations research problems – the Maximal Covering Location Problem (MCLP, Church and ReVelle 1974, Church *et al*. 1996) and the Location Set Covering Problem (LSCP; Bryan 2003). In the MCLP, the solution is constrained by the total amount of money or area available for conservation and the objective function tries to maximise the conservation value of the reserves. In the LSCP, the solution is constrained by having to meet certain conservation targets and the objective function aims to minimise the cost of the reserve system. We use the LSCP formulation as the decision rule for NRM in this study. Optimisers used to solve this problem include techniques ranging from random search algorithms to more sophisticated techniques that conduct a more structured search of the decision space such as heuristic algorithms, genetic algorithms, simulated annealing and mathematical programming.

The application of spatial optimisation in natural resource management has focused mainly on the selection of reserves for the conservation of biodiversity (Underhill 1994, Csuti *et al*. 1997, Possingham *et al*. 2000, McDonnell *et al*. 2002, Cocks and Baird 1989, Saetersdal *et al*. 1993, Church *et al*. 1996, Williams and ReVelle 1996, Haight *et al*. 2000, ReVelle *et al*. 2002, Rodrigues and Gaston 2002, Perry *et al*. in review) although it has recently been used to manage ecosystem processes (Seppelt and Voinov 2004). Spatial optimisation is being increasingly applied to landscape restoration (Bryan 2003; Bryan *et al*. 2004b; Crossman and Bryan in review). In this study, we expand the use of these techniques to systematic regional planning for multiple objective natural resource management.

In spatial optimisation, mathematical programming techniques usually take the form of integer programming where each spatial unit (grid cell, site or polygon) can either be included in or excluded from some action (such as vegetation management or reserve selection). Thus, each spatial unit can be either zero or one. IP has the advantage of being able to find guaranteed optimal solutions by the application of branch-and-bound algorithms developed in operations research (see Kingsland, 2002). Integer programming has not been widely used in spatial optimisation because the problems are *np hard*. In other words the size of the problem increases exponentially with the number of sites available. Spatial databases are often characterized by many thousands or even millions of sites, potentially placing traditional IP beyond the realm of solvability. However, new proprietary algorithms and significantly faster computer processors have greatly increased the tractability of IP problems (Rodrigues and Gaston 2002, Bryan 2003) and made them a viable option for spatial optimisation.

As the decision rules of the MCDA we present three spatial optimisation models for prioritising the three NRM actions in the Corridor - Vegetation Management, Revegetation for Biodiversity, and Revegetation for Biomass. Together, the models identify the most cost-effective sites for each NRM action that meets explicit resource condition targets.

The integer programming models used in this study were written in the General Algebraic Modelling System (GAMS) using the CPLEX solver. CPLEX has been found to be efficient in its solution of large-scale linear IP problems in conservation planning (Church *et al*. 1996, Ando *et al*. 1998, Rodrigues and Gaston 2002). Attribute data is assembled in a GIS (see earlier sections) and exported to tabular format for input into GAMS. Outputs are exported from GAMS in tabular format suitable for input back into the GIS for visualization and mapping.

5.4.1 Remnant Vegetation Management

5.4.1.1 Methods

In setting geographic priorities for vegetation management we need to select sites that satisfy NRM objectives at the same time as minimising the cost of the system. The Vegetation Management attributes described in Section 5.1.2.1.1 are suitable for use in either the objective function as a cost layer, or as a constraint. In addition to the vegetation management attributes, we combine opportunity costs and other NRM attributes into the model of vegetation management as costs and constraints.

Each attribute layer in the objective function is set up as a cost layer with cost scores between 1 and 5 with the most desirable characteristics having the lowest cost and the least desirable characteristics having the highest cost. Constraint layers are formatted in a site x features matrix.

The overarching resource condition target affecting remnant vegetation management is that 50% of remnant vegetation on private land in the Corridor should be managed. This is the driving constraint. We extend this constraint by implementing the conservation principle of representativeness. We suggest that, of the vegetation remaining on private land and in existing reserves, we should aim to manage 50% of each remnant vegetation community and rare and threatened species habitat, in addition to 50% of the remnant vegetation occurring in each climate zone. There are 125 vegetation communities, 11 significant species habitats, and 8 climate zones totaling 144 individual *features* to be represented by vegetation management. We also apply the two extra NRM constraints. These are that all Long-Term Eroding Land and the 10,000 ha of the highest salinity benefit areas (or simply *Salinity Benefit Areas*) under remnant vegetation are managed. Vegetated Areas and Private Land layers are also included as constraints. The costs and constraints are listed in Table 23.

Cost Layers in Objective Function		**Constraint Layers**	
Attribute	**Use**	**Attribute**	**Use**
Area	Bigger patches better	Vegetation Communities	50% managed on private land
Shape	Simple shape better	Significant Species Habitats	50% managed on private land
Fragmentation	Least fragmented better	Climate Zones	50% managed on private land
Habitat Quality	Further from patch edge better	Long-Term Eroding Land	All vegetated LTE areas managed on private land
Opportunity Costs	Lower cost better	Salinity Benefit Areas	All vegetated salinity benefit areas managed on private land
Wind Erosion Potential	Higher erosion potential better	Vegetated Areas	Only vegetated areas can be managed
		Private Land	Only private land can be managed
		Protected Areas	Protected areas already managed

Table 23 – Description of the layers used in setting geographic priorities for vegetation management in MCDA.

The number of grid cells (*m*) in the Corridor is 188,655. The total number of features (*n*) equals 146. An *m* x *n* matrix **A** (188,655 rows (grid cells) x 146 columns (features)) was created whose elements a_{ij} are given a binary value according to the presence or absence of each feature (*j*) at each grid cell (*i*). Grid cells are given a value of one if it supports a particular feature, zero otherwise such that:

$$a_{ij} = \begin{cases} 1 \text{ if feature } j \text{ occurs at grid cell } i \\ 0 \text{ otherwise} \end{cases}$$

for $i = 1 \ldots m$ and $j = 1 \ldots n$

A second matrix **B** (188,655 rows x 3 columns) is also created which holds the mask constraints of land cover, land tenure and conservation status. The land cover constraint is whether the cell is Vegetated or not (*V*), the land tenure constraint is whether the grid cell is Private Land (*PL*) or not and the conservation status is whether the grid cell is Protected or not (*P*). This information is used to mask out particular grid cells for vegetation management. The elements of **B**, b_{ik} are given a binary value according to the presence or absence of each particular mask constraint (*k*) at each grid cell (*i*). A grid cell is given a value of one if it supports a particular mask constraint, zero otherwise such that:

$$b_{ik} = \begin{cases} 1 \text{ if mask constraint } k \text{ occurs at grid cell } i \\ 0 \text{ otherwise} \end{cases}$$

for $i = 1 \ldots m$ and $k = V$, PL, and P

Next, a variable is defined that reflects whether or not a site is selected for vegetation management, as the vector **X** with dimension *m* and elements x_i, given by:

$$x_i = \begin{cases} 1 \text{ if site } i \text{ is selected for vegetation management} \\ 0 \text{ otherwise} \end{cases}$$

for $i = 1 \ldots m$

The objective function for the vegetation management model is an aggregate index comprised of the attribute layers listed in Table 23. The objective function minimises the total cost of the sites selected for vegetation management. Thus, considering the scaling of each attribute (as described in Section 5.1.2.1.1 the model selects the combination of sites for vegetation management that belong to patches of largest Area (*A*) and simplest Shape (*S*) and that are least Fragmented (*F*), it also selects sites that are of higher Habitat Quality in the interior of patches (*HQ*), have lowest Opportunity Costs (*OC*) and highest Wind Erosion Potential (*E*). Each layer has equal influence of the selection of grid cells. Criterion weights (*w*) may be adjusted so specific layers are more influential.

The objective function is then to:

$$\text{Minimise} \quad \sum_{i=1}^{m} x_i \left(A_i.w_A + S_i.w_S + F_i.w_F + HQ_i.w_{HQ} + OC_i.w_{OC} + E_i.w_E \right)$$

subject to the following constraints:

i) vegetation management can not occur in cleared areas:

if $b_{iV} = 0$, $x_i = 0$, for $i = 1,2,...,$m,

ii) existing protected areas of remnant vegetation are managed:

if $b_{iV} .b_{iP} = 1$, $x_i = 1$, for $i = 1,2,...,$m,

iii) public land not in reserves cannot be managed:

if $b_{iP} + b_{iPL} = 0$, $x_i = 0$, for $i = 1,2,...,$m,

iv) all Long-Term Eroding Land areas covered by remnant vegetation are managed:

if $b_{iV} .a_{ij} = 1$, $x_i = 1$ for j = 145 (LTE land), i = 1,2,...,m,

v) all salinity benefit areas covered by remnant vegetation are managed:

if $b_{iV} .a_{ij} = 1$, $x_i = 1$ for j = 146 (Salinity Benefit Areas), i = 1,2,...,m,

vi) at least 50% of native vegetation on private land is managed:

$$\frac{\sum_{i=1}^{m} b_{iV}.b_{iPL}.x_i}{\sum_{i=1}^{m} b_{iV}.b_{iPL}} \times 100 \geq 50$$

vii) of the remnant vegetation either protected or on private land… at least 50% of each Vegetation Community, 50% of each Significant Species Habitat, and 50% of each Climate Zone is managed:

$$\frac{\sum_{i=1}^{m} a_{ij}.b_{iV}.x_i}{\sum_{i=1}^{m} a_{ij}.b_{iV}} \times 100 \geq 50 \quad \text{for } j = 1,2,\ldots,n,$$

where $a_{ij}, x_i \in \{0,1\}$, $b_{iP} = 1$ or $b_{iPL} = 1$.

Four different analyses are run to assess the influence of using different attributes in the objective function and constraints on areal and cost indicators. Model 1 simply finds the set of cells for vegetation management that satisfies the broad regional target of managing 50% of native vegetation on private land at the minimum Opportunity Costs. It is the cheapest way of reaching resource condition targets. Model 2 extends Model 1 to include the representativeness targets for biodiversity (50% of each Vegetation Community, Climate Zone and Significant Species Habitat) and minimises Opportunity Costs. Model 3 extends Model 2 to include the natural resource management targets of Salinity Benefit Areas and Long-Term Eroding Land. Model 3 also minimises opportunity costs. Model 4 extends Model 3 and extends the attributes in the objective function to include not only Opportunity Costs but also the landscape ecology costs of patch Area and Shape, Fragmentation and Habitat Quality, and Wind Erosion Potential. By assessing these four models we can quantify the trade-offs involved with including systematic regional planning principles in the setting of geographic priorities for achieving INRM targets. The four models are summarised:

Model 1 – Regional 50% vegetation on private land managed, minimise Opportunity Costs

Model 2 – Regional 50% target, plus 50% representativeness targets, minimise Opportunity Costs

Model 3 – Regional 50% target, 50% representativeness targets, NRM targets, minimise Opportunity Costs

Model 4 - Regional 50% target, 50% representativeness targets, NRM targets, minimise function of Opportunity Costs, Area, Shape, Fragmentation, Habitat Quality, and Wind Erosion Potential

5.4.1.2 Results

The outcomes of the MCDA model are mapped geographic priorities for vegetation management in the Corridor. The Corridor supports approximately 510,734 ha of remnant vegetation or nearly 42% of the total area. This is a high percentage compared to other agricultural regions in South Australia. A high proportion (over 80%) of the remnant vegetation is on privately owned land. Over 176,760 ha are protected or managed for conservation, representing 14.5% of the Corridor. Over 60% of this is on private land. Thus, over 25% of remnant vegetation on private land is already managed under either Heritage Agreements or as part of the Bookmark Biosphere Reserve. To meet the NRM resource condition targets this needs to increase to 50% (Table 24). In other words, reaching the regional resource condition target will require a doubling of the existing area of remnant vegetation on private land that is managed for conservation.

However, the current protection of remnant vegetation is not representative of the different biological and physical environments of the Corridor. Most of the protected areas occur in the driest climates and on the poorest soils, especially the Mallee and rangeland regions north of the stretch of river between Waikerie and the border. The Bookmark Biosphere Reserve, which includes several NPWS reserves, is the largest protected/managed area in the Corridor. Other significant protected areas are located west of Blanchetown (Figure 55). However, protected areas cover a much lower fraction of the total remnant vegetation in other parts of the Corridor particularly around Morgan and in the better agricultural areas south and east of the River Murray (Figure 55).

Current Status	**Results**
Total area of remnant vegetation	510,734 ha
Total area of privately owned remnant vegetation	413,489 ha
Total area of remnant vegetation currently protected/managed	176,760 ha
Total area of privately owned remnant vegetation currently protected/managed	106,993 ha
Total area of publicly owned remnant vegetation currently protected/managed	69,767 ha

Table 24 – Baseline information about the conservation status and land tenure for comparison with MCDA model outputs for vegetation management.

All models meet the regional target of managing 50% of remnant vegetation on private land in the Corridor – a total of 99,751 ha of newly managed remnant vegetation. This sums to 206,745 ha including existing managed vegetation on private land in Heritage Agreement Areas, and 276,512 ha when public reserves are also included (Table 25). The establishment costs of meeting the resource condition target for vegetation management based on a low and high estimate of costs per hectare ranges from $49 Million to $300 Million. Putting these figures in context, the establishment costs and opportunity costs of implementing resource condition targets in the Corridor are many times greater than any amount of funding likely to become available for on-ground works in the foreseeable future. Smart market-based policy is required to have any chance of reaching regional NRM targets for vegetation management.

Post Planning Indicators	Model 1	Model 2	Model 3	Model 4
Total new area of managed remnant vegetation	99,751 ha	99,751 ha	99,751 ha	99,751 ha
New area of privately owned remnant vegetation protected/managed	99,751 ha	99,751 ha	99,751 ha	99,751 ha
New area of publicly owned remnant vegetation protected/managed	0 ha	0 ha	0 ha	0 ha
Total area of vegetation protected/managed	276,512 ha	276,512 ha	276,512 ha	276,512 ha
Total area of privately owned remnant vegetation protected/managed	206,745 ha	206,745 ha	206,745 ha	206,745 ha
Mean Area cost score of new vegetation management areas	1.09	1.39	1.39	1.44
Mean Fragmentation cost score of new vegetation management areas	1.56	2.09	2.10	1.93
Mean Shape cost score of new vegetation management areas	4.84	4.35	4.33	3.79
Mean Habitat Quality cost score of new vegetation management areas	3.94	4.38	4.39	4.30
Mean Wind Erosion Potential cost score of new vegetation management areas	4.25	4.46	4.46	4.28
Proportion of Long-Term Eroding Land managed	4.08 %	13.78 %	22.11 %	22.11 %
Proportion of Salinity Benefit Areas managed	0.39 %	0.58 %	1.87 %	1.87 %
Value of annual Opportunity Costs of newly managed remnant vegetation areas	$1,204,297	$1,286,221	$1,286,224	$1,326,194
Establishment costs of vegetation management **LOW EST. ($500 / ha)**	$49,875,500	$49,875,500	$49,875,500	$49,875,500
Establishment costs of vegetation management **HIGH EST. ($3,000 / ha)**	$299,253,000	$299,253,000	$299,253,000	$299,253,000

Table 25 – Post planning indicators of the four models assessed in this study.

Model 1 has identified the set of grid cells for vegetation management that meets the regional target of 50% of remnant vegetation on private land managed at the minimum opportunity cost of $1,204,297 per year (Table 25). The cells with the lowest opportunity cost are selected until the 50% target is reached. These cells are those in the driest climate areas north of Morgan (Figure 56). Whilst this Model significantly improves the representativeness of vegetation managed around the Morgan area, other areas in the Corridor are not selected for management and the subsequent cover of biophysical diversity is poor (Figure 56). There is also very little spatial cohesiveness in the areas selected for management outside of the large patch near Morgan. If all of these areas were to be fenced off and managed it would result in much larger areas being taken out of production and larger opportunity costs. By coincidence, the cells selected in Model 1 have mean scores that suggest they tend to cover large intact patches with poor shape index, reasonable habitat quality and lower wind erosion potential (although the latter is common throughout remnant vegetation in the Corridor). This is purely coincidence and typifies the remnant vegetation patches in the area north of Morgan where the cells are concentrated. The cells selected in Model 1 provide only minimal benefits for Long-Term Eroding Land (4% covered) and Salinity Benefit Areas (0.39% covered, Table 25).

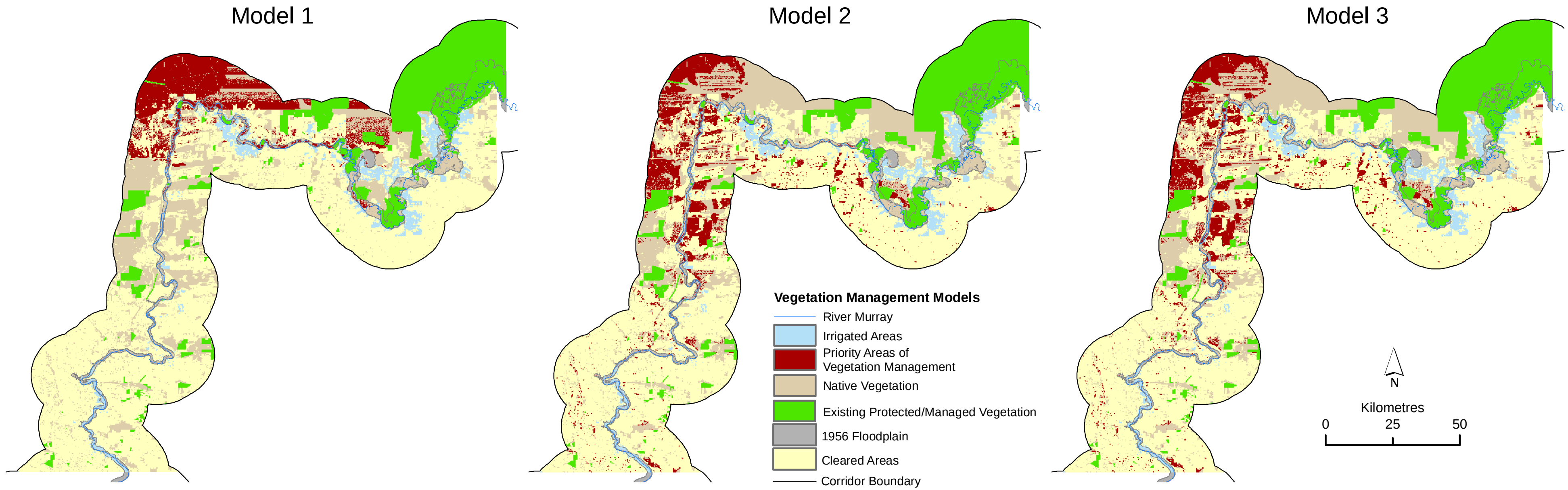

Figure 56 – Geographic priorities for Vegetation Management in the Corridor identified by Models 1-3.

Model 2 is a more ecologically sustainable solution because it incorporates the principle of representativeness. Managed areas of vegetation cover 50% of each Vegetation Community, Significant Species Habitat and Climate Zone, and are therefore more likely to cover a larger range of biodiversity than aiming for the least expensive way to meet vegetation management targets (Model 1). Cells selected for management include vegetation patches distributed over the entire Corridor (Figure 56). The opportunity costs are only $84,000 (7%) higher than the cheapest option in Model 1. The inclusion of representativeness targets provides much greater natural resource management benefits for only minimal extra cost.

Mean cost scores for the landscape ecological indicators of Area, Fragmentation and Habitat Quality are poorer than Model 1 but the Shape score is better. This is because the representativeness targets force selection of smaller patches of vegetation for management rather than concentration in a large patch. Wind erosion potential score is also poorer because the higher clay content soils in the south are selected for management. Significantly greater benefits are gained for Long-Term Eroding Land (13.8%) and Salinity Benefit Areas (0.6%) (Table 25).

The output of Model 3 is very similar to Model 2 when considering all indicators (Table 25). This is because the two models use the same objective function and constraints except that Model 3 includes managing all vegetated Long-Term Eroding Land and Salinity Benefit Areas. This results in a substantial increase in the proportion of the total Long-Term Eroding Land and Salinity Benefit Areas that is managed (22% and 1.87%, respectively, Table 25). The extra Opportunity Cost of managing vegetation on Long-Term Eroding Land and Salinity Benefit Areas is only $4 per year. The geographic priorities are very similar to Model 2 (Figure 56). Thus, NRM targets can be incorporated into systematic regional planning for vegetation management at little extra biophysical or economic cost.

Model 4 includes extra attributes in the objective function to enhance the spatial location of cells selected for remnant vegetation management. They are guided by landscape ecological principles and the prioritisation of vegetation management on areas of high Wind Erosion Potential. Model 4, as with Models 2 and 3, includes representative proportions of each Vegetation Community, Climate Zone and Significant Species Habitat (Table 26). The solution offers significant improvements because the objective function is a weighted aggregate index comprised of the Area, Shape, Fragmentation, Habitat Quality, Opportunity Costs, and Wind Erosion Potential. Fragmentation, Shape, Habitat Quality, and Wind Erosion Potential cost scores are lower than Model 3 but the trade off is the higher Area cost score. Whilst the solution does not represent the least expensive financial option, the extra Opportunity Cost of enhancing the spatial arrangement of grid cells for extra natural resource management benefits is only $40,000 per year (3%) more than not including them (Table 25). Again, the inclusion of smart targeting according to established systematic principles can result in significant NRM benefits at minimal extra cost.

However, the spatial arrangement of selected cells is variable (Figure 57). In many parts of the Corridor entire patches are selected for management. Often, grid cells are selected for management that also buffer and link adjacent protected/managed areas. These should be seen as priority areas because they are simplest to implement. Many shapes are complex and impractical for implementing vegetation management. We later recommend policy options that provide a practical way to target high priority land in an iterative way.

Vegetation Community	% Rep. Before	% Rep. After
1	0.0	50.0
2	11.0	50.0
3	0.0	50.0
4	100.0	100.0
5	36.4	50.0
6	92.3	92.3
7	15.2	50.0
8	0.0	50.0
9	0.0	50.0
10	93.9	93.9
11	85.1	85.3
12	0.0	50.0
13	67.9	68.7
14	21.4	50.0
15	72.5	73.9
16	0.0	50.0
17	0.0	50.0
18	21.9	50.0
19	1.9	50.0
20	0.0	50.0
21	26.0	50.0
22	9.4	50.0
23	18.6	50.0
24	83.3	83.3
25	86.4	86.4
26	96.1	96.1
27	14.7	50.0
28	78.9	84.2
29	79.2	79.9
30	0.0	50.0
32	95.9	95.9
33	1.6	50.0
34	0.0	50.0
35	0.0	50.0
36	0.0	50.0
37	0.0	50.0
38	0.0	50.0
39	79.3	82.8
40	42.3	50.0
41	100.0	100.0
42	73.2	74.6
43	72.7	77.3
44	69.0	74.1
45	55.0	57.8
47	72.9	78.1
48	46.1	50.9
49	34.5	51.3
50	64.2	68.7
51	52.6	52.6
52	45.5	54.5
53	10.4	50.0
54	55.0	55.0
55	57.8	62.2
56	0.0	50.0
57	21.1	50.0
58	0.0	50.0
59	20.7	50.0
60	60.2	63.2
61	31.3	50.0
62	17.2	50.0
63	82.4	82.4
64	37.5	50.0
65	72.7	76.6
66	82.0	82.8
67	0.0	50.0
68	86.6	86.6
69	37.5	50.0
70	78.6	78.6
71	42.1	50.0
72	48.4	50.8
73	0.0	100.0
74	16.5	50.0

Vegetation Community (cont.)	% Rep. Before	% Rep. After
75	33.3	50.0
76	0.0	50.0
77	0.0	50.0
79	1.2	50.0
80	7.4	50.0
81	50.7	57.4
83	16.3	50.0
84	57.1	61.4
85	46.9	50.0
86	41.5	50.0
87	0.0	50.0
88	0.0	50.0
90	0.0	50.0
91	0.0	50.0
92	0.0	50.0
93	2.9	50.0
94	97.4	97.4
95	0.0	100.0
96	58.3	63.8
97	0.0	50.0
98	0.0	50.0
99	0.9	50.0
100	44.4	50.0
101	0.0	50.0
103	80.9	81.9
104	4.5	50.0
105	17.4	50.0
106	0.0	50.0
107	77.8	81.5
108	0.0	50.0
109	66.5	66.8
110	50.9	51.7
111	47.1	50.0
112	0.0	50.0
113	18.7	50.0
114	85.7	85.7
115	30.1	50.0
116	31.8	50.0
117	0.0	50.0
118	54.5	63.6
119	66.7	66.7
120	76.5	77.0
121	94.1	94.1
122	0.0	50.0
123	37.7	50.0
124	1.8	50.0
125	0.0	50.0
126	38.5	50.0
127	3.2	50.0
128	39.3	50.0
129	0.0	50.0
130	0.0	50.0
131	50.0	50.0

Climate Zones	% Rep. Before	% Rep. After
1	17.7	50.0
2	62.5	70.8
4	44.1	59.9
6	12.6	52.4
7	0.0	50.0
10	18.9	57.1
11	0.0	50.0

Significant Species Habitat	% Rep. Before	% Rep. After
Black-eared miner	55.3	61.3
Chestnut quail	41.7	57.0
Common dunnart	34.8	54.0
Striated grass wren	55.0	61.9
Major Mitchell cockatoo	55.9	63.5
Mallee fowl	52.2	60.1
Red-lored whistler	68.1	72.3
Regent parrot	44.0	60.8
Southern hairy-nosed wombat	15.7	50.0
Striped honeyeater	47.4	60.4
Western pygmy possum	25.3	51.9

Table 26 – Representativeness of Vegetation Communities, Climate Zones and Significant Species Habitat of existing managed/protected remnant vegetation (Before) and after implementation of Model 4. Model 4 includes the representativeness targets as do Models 2 and 3.

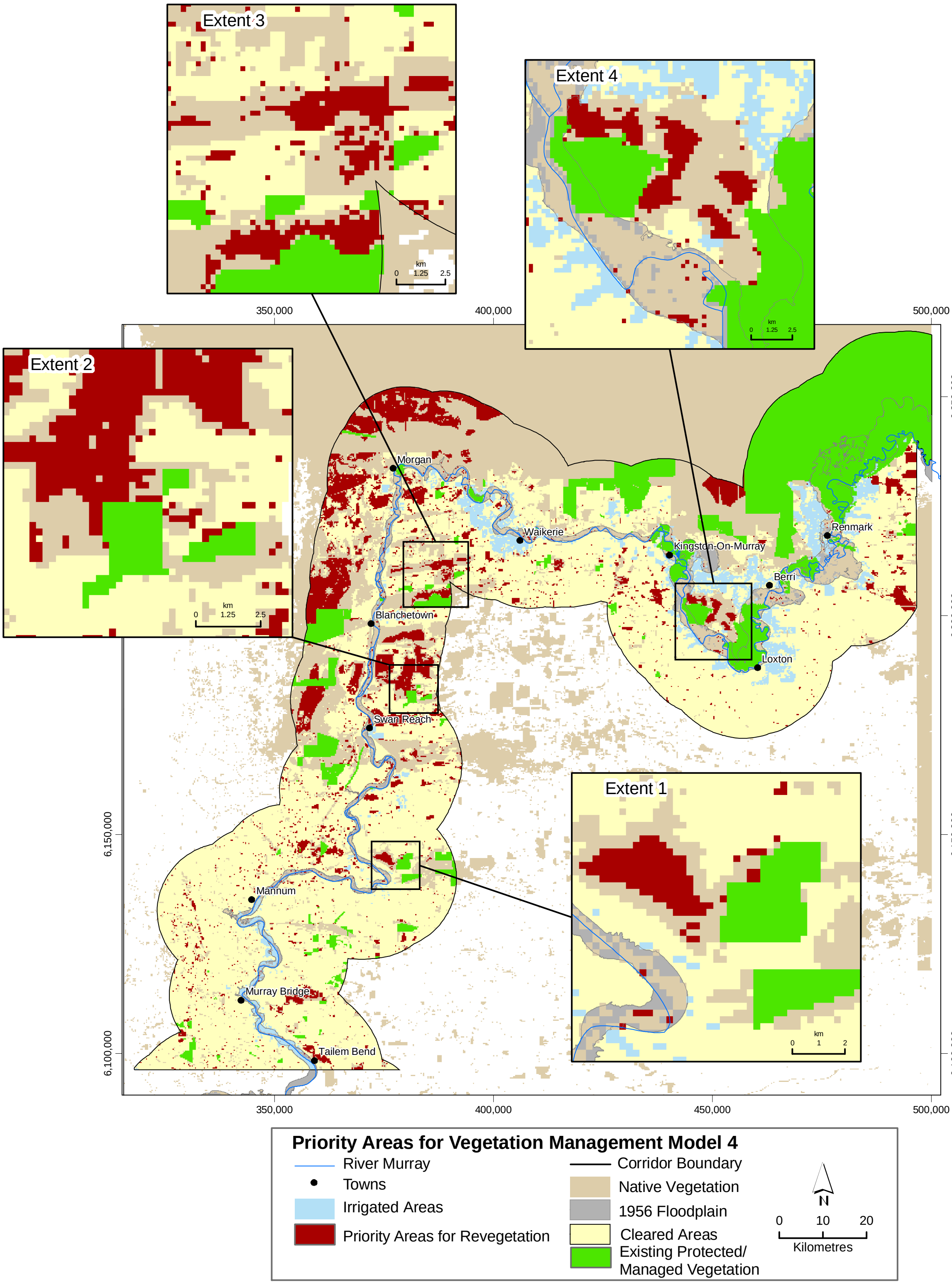

Figure 57 – Geographic priorities for vegetation management identified by Model 4. The insets zoom in on four areas of interest that display the relationship between areas selected for vegetation management, existing remnant vegetation and existing protected/managed areas.

5.4.2 Revegetation for Biodiversity

5.4.2.1 Methods

When setting geographic priorities for revegetation for biodiversity we need to select sites that satisfy NRM objectives whilst minimising the cost of the system. The revegetation for biodiversity attributes described in Section 5.1.2.1.2 are suitable for use in either the objective function as a cost layer or as a constraint. In addition to these attributes (Landscape Context, Fragmentation, Pre-European Vegetation Communities, Climate Zones and Soil Land Systems), we integrate Opportunity Costs and the NRM attributes of Wind Erosion Potential, Long Term Eroding Areas and Salinity Benefit Areas into the model of revegetation for biodiversity as costs and constraints.

The primary regional resource condition target states that revegetation for biodiversity should increase the area of existing vegetation by 1%. Increasing the area of vegetation by 1% would involve the revegetation/restoration of just over 5,100 ha. There is no further information guiding where revegetation for biodiversity should occur. This target is not based on any ecological or conservation planning principles. Revegetation of this area will not ensure representativeness targets are met. This is a very expensive exercise and needs to occur in high priority regional sites in order to have maximum benefit for biodiversity. The priority areas need to be identified systematically using established conservation principles.

The setting of a 1% increase target in the SA MDB is a departure from other target setting for conservation and revegetation in Australia. National Forest Policy aims to conserve 15% of each bioregion (JANIS 1997). Extending the 1% target, we take a longer term view in this study to ensure compatibility with national conservation goals. Priority sites for revegetation are identified that, together with existing remnant vegetation, ensure 15% of each Pre-European Vegetation Community, Climate Zone and Soil Land System are represented. These targets are set as constraints in the MCDA models. The 1% target can remain in place as a short term goal. However, sites selected in the short term should contribute to the longer term 15% representativeness target.

Thus, the constraints implement the conservation principle of representativeness in setting geographic priorities for revegetation. We suggest that the long-term goal of revegetation in the Corridor should be to target sites that together with existing remnant vegetation represents 15% of each of the 23 Pre-European Vegetation Communities, 8 Climate Zones, and 61 Soil Land Systems. We also apply the two extra NRM constraints that specify that all Long-Term Eroding Land and all Salinity Benefit Areas on cleared, non-irrigated land should be revegetated. This totals 94 individual *features* to be represented by existing vegetation and revegetation. Vegetated Areas and Private Land layers are also included as constraints. The costs and constraints are listed in Table 27.

Cost Layers in Objective Function		**Constraint Layers**	
Attribute	**Use**	**Attribute**	**Use**
Landscape Context	Cells closer to remnant vegetation better	Pre-European Vegetation Communities	15% vegetated
Fragmentation	Fragmented best, then relictual, variegated, and intact	Climate Zones	15% vegetated
Opportunity Costs	Lower cost better	Soil Land Systems	15% vegetated
Wind Erosion Potential	Higher erosion potential better	Long-Term Eroding Land	All Long-Term Eroding Land vegetated
		Salinity Benefit Areas	All Salinity Benefit Areas vegetated

Table 27 – Description of the layers used in setting geographic priorities for revegetation for biodiversity in MCDA.

Again, each attribute layer in the objective function is set up as a cost layer with cost scores between 1 and 5, with the most desirable characteristics having the lowest cost and the least desirable characteristics having the highest cost: Constraint layers are formatted in a site x features matrix where each grid cell is a site and each constraint class (each Pre-European Vegetation Community, Climate Zone, Soil Land System, NRM attribute) is a feature. The elements of the matrix are given a binary digit (0 or 1) depending on whether the feature occurs at the site.

The optimisation problem for revegetation for biodiversity is formulated in the same manner as the vegetation management problem. The number of grid cells (*m*) in the Corridor is 188,655. The total number of features (*n*) equals 92. An *m* x *n* matrix **A** (188,655 rows (grid cells) x 94 columns (features)) was created whose elements a_{ij} are given a binary value according to the presence or absence of each feature (*j*) at each grid cell (*i*). Grid cells are given a value of one if it supports a particular feature, zero otherwise such that:

$$a_{ij} = \begin{cases} 1 \text{ if feature } j \text{ occurs at grid cell } i \\ 0 \text{ otherwise} \end{cases}$$

for $i = 1 \ldots m$ and $j = 1 \ldots n$

A second matrix **B** (188,655 rows x 2 columns) is also created which holds two land cover mask constraints. The land cover constraints describe whether the cell is Vegetated or not (*V*) and whether the grid cell is Irrigated or not (*I*). This information is used to mask out particular grid cells for revegetation. The elements of **B**, b_{ik} are given a binary value according to the presence or absence of each particular mask constraint (*k*) at each grid cell (*i*). Grid cells are given a value of one if it supports a particular mask constraint, zero otherwise such that:

$$b_{ik} = \begin{cases} 1 \text{ if mask constraint } k \text{ occurs at grid cell } i \\ 0 \text{ otherwise} \end{cases}$$

for $i = 1 \ldots m$ and $k = V$ and I

Next, a variable is defined that reflects whether or not a site is selected for revegetation, as the vector **X** with dimension *m* and elements x_i, given by:

$$x_i = \begin{cases} 1 \text{ if site } i \text{ is selected for revegetation} \\ 0 \text{ otherwise} \end{cases}$$

for $i = 1 \ldots m$

In accord with the vegetation management models, the objective function for the revegetation model is an aggregate index comprised of the attribute layers listed in Table 27. The objective function minimises the total cost of the sites selected for revegetation. Thus, considering the scaling of each attribute as described in Section 5.1.2.1.2, the model selects the combination of grid cells for revegetation that have the most favourable Landscape

Context (LC) or in other words, are closest to existing remnant vegetation patches. In addition, the model selects grid cells that have the most appropriate Fragmentation status (*F*), lowest Opportunity Costs (OC), and highest Wind Erosion Potential (E). Each layer has equal influence of the selection of grid cells. Criterion weights (*w*) may be adjusted so specific layers are more influential.

The objective function is then to:

Minimise $$\sum_{i=1}^{m} x_i (LC_i.w_{LC} + F_i.w_F + OC_i.w_{OC} + E_i.w_E)$$

subject to the following constraints:

i) revegetation can not occur in existing areas of remnant vegetation:

if $b_{iV} = 1$, $x_i = 0$, for $i = 1,2,...,m$,

ii) revegetation can not occur in irrigated areas:

if $b_{iI} = 1$, $x_i = 0$, for $i = 1,2,...,m$,

iii) all non-vegetated Long-Term Eroding Land areas are revegetated:

if $b_{iV} = 0$ and $a_{ij} = 1$, $x_i = 1$ for $j = 93$ (LTE land), $i = 1,2,...,m$,

iv) all non-vegetated Salinity Benefit Areas are revegetated:

if $b_{iV} = 0$ and $a_{ij} = 1$, $x_i = 1$ for $j = 94$ (SC land), $i = 1,2,...,m$,

v) minus the irrigated areas, at least 15% of each Pre-European Vegetation Community, 15% of each Soil Land System, and 15% of each Climate Zone is either represented by existing remnant vegetation or revegetated:

$$\frac{\sum_{i=1}^{m} a_{ij}.b_{iV} + \sum_{i=1}^{m} a_{ij}.x_i}{\sum_{i=1}^{m} a_{ij} - \sum_{i=1}^{m} b_{iI}.a_{ij}} \times 100 \geq 15$$

for $j = 1,2,\ldots,n$,

where $a_{ij}, x_i \in \{0,1\}$

Five different revegetation Models were run to assess the influence of using different attributes in the objective function and constraints on a suite of areal, biophysical and economic indicators. Model 1 selects the grid cells for revegetation that satisfy the broad regional target of increasing remnant vegetation by 1% at the minimum Opportunity Costs. It is the cheapest way of reaching the stated resource condition target. Model 2 implements the more sophisticated representativeness targets for revegetation for biodiversity (15% of each Pre-European Vegetation Community, Climate Zone, and Soil Land System) and minimises Opportunity Costs. Model 3 extends Model 2 by integrating a more extensive suite of cost attributes in the objective function. These attributes include not only Opportunity Costs but also the landscape ecological attributes of Landscape Context and Fragmentation, and the natural resource management attribute of Wind Erosion Potential. Model 4 also extends Model 2 to include the natural resource management targets of Salinity Benefit Areas and Long-Term Eroding Land at the minimum Opportunity Costs. Model 5 combines Models 3 and 4 and includes both the NRM targets and the extensive suite of cost attributes in the objective function. By assessing these 5 models we can quantify the trade-offs involved with including systematic regional planning principles in the setting of geographic priorities for achieving NRM targets. The 5 models are summarised below:

Model 1 – Regional 1% revegetation target, minimum opportunity cost

Model 2 – 15% representativeness targets, minimum opportunity cost

Model 3 - 15% representativeness targets, minimise function of Opportunity Cost, Landscape Context, Fragmentation, and Wind Erosion Potential

Model 4 – 15% representativeness targets, NRM targets, minimum opportunity cost

Model 5 - 15% representativeness targets, NRM targets, minimise function of Opportunity Cost, Landscape Context, Fragmentation, and Wind Erosion Potential

5.4.2.2 Results

Spatial optimisation in MCDA was able to identify sites for revegetation for biodiversity according to the objectives in Models 1 to 5. The resource condition target of increasing the area of native vegetation by 1% remains a reasonable short-term target. However, we recommend that this increase in area should be part of a longer term goal based on sound ecological and conservation planning principles. The five models assess the costs and benefits of increasing the sophistication of targets for revegetation for biodiversity and included representativeness targets, landscape ecological targets and NRM targets.

Superficially, the extent of remnant vegetation in the Corridor is sufficient because over 42% of the region remains in a relatively natural state. However, the remnant vegetation is not representative of the full range of biophysical diversity. Most of the remnant vegetation is concentrated in the northern parts of the Corridor in the drier climates less suitable for broadacre cropping. Much of the Mallee and rangeland environments north of the River Murray between Morgan and the border are under remnant vegetation. Areas to the south of this stretch of river have been extensively cleared. Also, large tracts of Mallee and native grasslands remain both sides of the River Murray between Swan Reach and Morgan. Areas to the south of Swan Reach have also been extensively cleared. The revegetation targets used in this model identify areas for revegetation so that all biophysical environment types are represented by native vegetation Table 28.

Soil Land Systems	% Rep. Before	% Rep. After
164	2.473	15
211	61.874	61.874
288	63	63
297	58.037	58.037
298	86.366	86.366
316	58.077	61.938
317	29.264	29.264
319	43.802	43.925
320	99.732	99.732
326	24.3	27.054
327	43.847	44.367
336	89.206	89.206
340	62.34	62.34
342	23.538	26.843
344	16.617	17.255
345	11.372	15
351	85.536	85.536
361	74.061	74.866
371	13.938	15.223
388	1.527	15
394	46.489	50.638
422	65.01	65.191
444	12.5	15
466	1.342	15
477	11.085	15
482	10.236	15
486	28.43	28.43
487	5.312	15
489	1.873	15
493	10.789	15
499	7.665	15
503	15.625	15.625
507	4.364	15
509	2.987	15
514	5.96	15
515	0.543	15
516	0	15
522	50.294	50.294
525	3.48	15
527	4.114	15
533	5.729	15
534	13.621	15
536	33.333	33.333
545	1.838	15
556	7.228	15
557	9.437	15
564	20	20

Soil Land Systems	% Rep. Before	% Rep. After
568	20	20
578	0	15
579	6.264	15
594	12.062	15
598	3.97	15
599	2.712	15
600	13.807	15
603	8.04	15
604	19.022	19.022
610	4.618	15
615	24.874	24.874
616	7.407	15
618	14.607	15
-9999	5.263	15
Climate Zones	**% Rep. Before**	**% Rep. After**
1	26.504	28.977
2	5.33	15
4	60.103	61.7
6	10.801	15.123
7	3.39	15
10	11.556	16.35
11	4.788	15
12	0	15
Pre-European Vegetation	**% Rep. Before**	**% Rep. After**
101	18.824	19.103
1101	14.389	16.557
1201	2.576	15
1401	23.148	28.435
1701	33.333	33.333
1801	15.454	16.992
1901	10.482	15
201	22.195	22.195
2802	52.812	53.125
3101	28.571	28.571
3301	41.346	48.077
3601	0	15
3701	5.036	15
3801	50.335	52.74
4001	0.554	15
4601	15.53	15.602
4701	5.983	15
5001	27.273	27.273
5101	50	50
601	19.512	31.707
801	11.222	15.729
901	31.258	33.333
Unknown	58.727	60.598

Table 28 – Level of representation of Pre-European Vegetation Communities, Climate Zones and Soil Land Systems by existing remnant vegetation (Before) and by remnant vegetation and revegetation after Model 5. Model 5 includes the representativeness targets as do Models 2, 3 and 4 which display similar levels of representation of biophysical features.

The establishment costs of reaching the 1% revegetation target (5,100 ha) range between $2.5 and $15 Million. Hence, this may be a realistic short term (5 – 10 yr) target. The 15% targets set in this study are long term goals for revegetation. As such, the cost of these goals, which for Model 5 range between $13.8 and $83 Million are not out of the realms of possibility as long term (20 – 30 yr) goals given currently levels of government funding. Market-based policy mechanisms may greatly enhance the likelihood that these revegetation goals are met and decrease the likely time period in which they might be met.

Model 1 implements the simple objective of increasing remnant native vegetation by 1% in the most cost effective way by minimising Opportunity Costs. This amounts to an area of revegetation of 5,107 ha. The minimum annual Opportunity Cost of meeting this target is $41,685. The areas selected for revegetation are concentrated in the north of the Corridor around Morgan and along the river between Waikerie and Kingston-on-Murray (Figure 58). These grid cells are the least expensive agricultural land and have minimal use or are grazed by sheep. The mean Landscape Context and Fragmentation scores by chance are very healthy but the mean Wind Erosion Potential score is high. The proportion of Long-Term Eroding Land and Salinity Benefit Areas vegetated (i.e. covered by both existing remnant vegetation and revegetation) are low (Table 29). The major criticism of this model is that the resulting areas of vegetation are not representative of the range of biophysical environments of the Corridor. The revegetation recommended under Model 1 is concentrated in those environments that are already over-represented in the Corridor. As a result, much of the biodiversity characteristic of unrepresented environments may not have the chance to flourish through the revegetation of local native species and the reconstruction of native habitats. Revegetation in these locations offers negligible biodiversity outcomes and would not be an effective use of conservation resources.

Post Planning Indicators	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Total area of existing remnant vegetation	510,734 ha	510,734 ha	510,734 ha	510,734 ha	510,734 ha
Total area of vegetation including revegetation	515,841 ha	532,312 ha	532,312 ha	566,595 ha	566,595 ha
Total area of revegetation	5,107 ha	21,578 ha	21,578 ha	27,681 ha	27,681 ha
Mean Landscape Context cost score of revegetated areas	1.05	1.24	1.03	1.21	1.07
Mean Fragmentation cost score of revegetated areas	1.33	1.61	1.32	1.48	1.3
Mean Wind Erosion cost score of revegetated areas	3.9	3.86	3.19	3.8	3.34
Proportion of Long-Term Eroding Land vegetated	31.6 %	30.61 %	36.74 %	98.3 %	98.3 %
Proportion of Salinity Benefit Areas vegetated	6.3 %	6.0 %	5.16 %	82.58 %	82.58 %
Value of annual Opportunity Costs of revegetated areas	$41,685	$705,936	$855,118	$920,957	$1,047,464
Establishment costs of revegetation **LOW EST. ($500 / ha)**	$2,553,500	$10,789,000	$10,789,000	$13,840,500	$13,840,500
Establishment costs of revegetation **HIGH EST. ($3,000 / ha)**	$15,321,000	$64,734,000	$64,734,000	$83,043,000	$83,043,000

Table 29 – Post planning indicators of the five revegetation models assessed in this study.

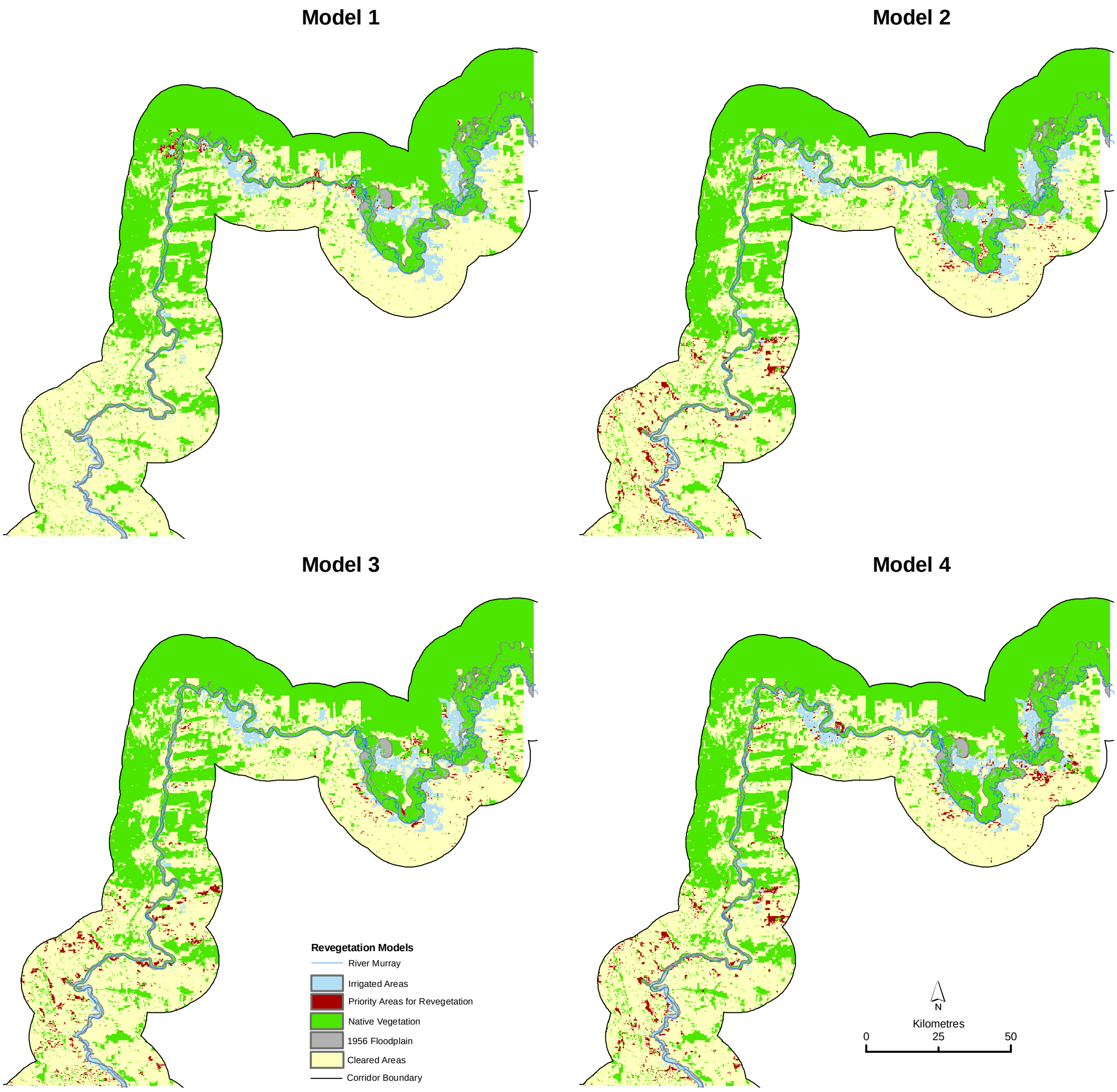

Figure 58 – Geographic priorities for revegetation in the Corridor identified by Models 1-4.

Model 2 is the simplest implementation of the 15% representativeness constraint. As such, the sites identified for revegetation by this model together with existing revegetation cover 15% of each Soil Land System, Climate Domain and Pre-European Vegetation Community (see Table 28) most cost effectively. Despite the relatively high proportion of remnant vegetation remaining in the Corridor, the targeting of certain environment types for land clearance for agriculture means that the Opportunity Costs of meeting representativeness targets in the Corridor are significant at nearly $706,000 per annum. The area of revegetation required represents an increase of the total area of native vegetation by more than 4% or 21,578 ha. The mean Landscape Context and Fragmentation cost scores are worse than Model 1 simply because there are 4 times more grid cells selected and the representativeness constraints are in force. The mean Wind Erosion Potential cost score is similar to Model 1 as are the proportions of both Long-Term Eroding Land and Salinity Benefit Areas (Table 29).

Model 3 includes the 15% representativeness targets and minimises a weighted linear function of Opportunity Costs, Landscape Context and Wind Erosion Potential scores. Model 3 involves revegetation of the same area as Model 2 but offers substantially better mean Landscape Context, Fragmentation and Wind Erosion Potential scores, better even than

Model 1. The Opportunity Costs of this improvement is nearly $150,000 per annum over Model 2 (a 21% increase) (Table 29).

Model 4 includes the 15% representativeness constraint and targets all Long-Term Eroding Land and Salinity Benefit Areas (not irrigated) at the minimum Opportunity Cost. Including the NRM constraints requires an extra 6,000 ha or 27,681 ha in total. The Opportunity Cost of Model 4 is nearly $920,000 per annum. Hence, the extra cost of meeting the NRM targets of revegetating Long-Term Eroding Land and Salinity Benefit Areas is around $215,000 per annum – a 30% increase (i.e. compare Model 4 with Model 2). The total Net Present Value of the costs to downstream users of river salinity avoided by revegetation is just over $3 Million over 100 years. Thus, the opportunity costs alone of revegetation are many times higher than the public benefits resulting from land degradation let alone the establishment costs. By chance, the indicators of mean Landscape Context, Fragmentation and Wind Erosion Potential cost scores are as good as or better than Model 2 which does not include NRM constraints of Long-Term Eroding Land and Salinity Benefit Areas (Table 29).

Model 5 is the most sophisticated multiple objective model and includes the 15% representativeness constraint and targets all Long-Term Eroding Land and Salinity Benefit Areas (not irrigated) and minimises a weighted linear function of Opportunity Costs, Landscape Context and Wind Erosion Potential cost scores. Model 5 requires the same area of revegetation as Model 4 but the Opportunity Costs of including the Landscape Context, Fragmentation and Wind Erosion Potential are around $147,000 per annum. The indicators are all very respectable for Model 5 (Table 29). The spatial distribution of areas for revegetation are a mix of new patches, infill of existing remnants, stepping stone patches and linking areas (Figure 59).

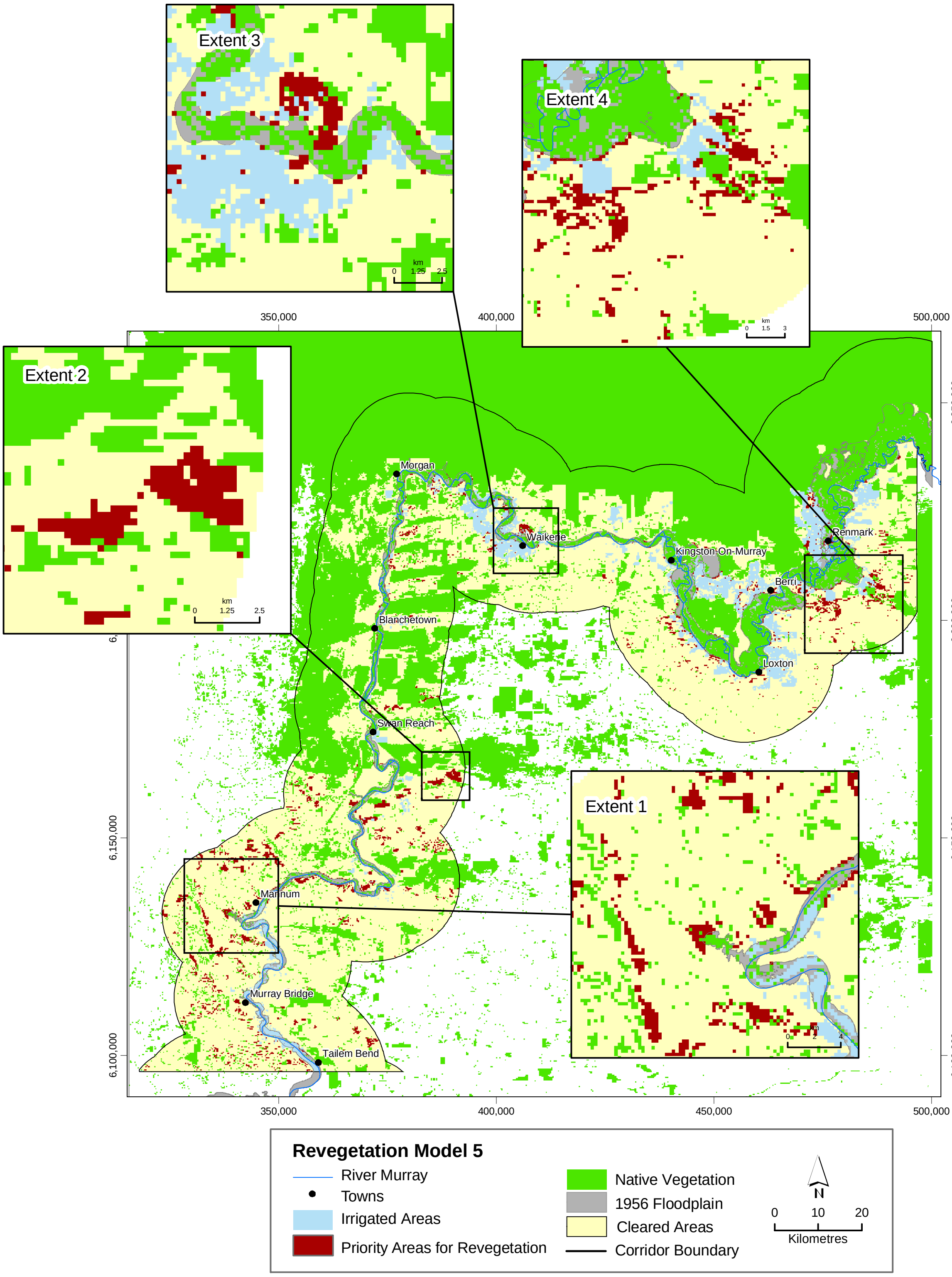

Figure 59 – Geographic priorities for revegetation in the Corridor identified by Model 5. The insets zoom in on 4 areas of interest where Model 5 has identified grid cells for revegetation that buffer, infill and link existing remnants.

5.4.3 Revegetation for Biomass

5.4.3.1 Methods

The optimisation models for both vegetation management and revegetation use the set covering model which covers a set of features to a specified level and tries to minimise the cost function. A variation on this model is used for identifying priority locations for biomass production. The biomass model takes an economic rationalist point of view and selects the locations that are most profitable and at the lowest risk. The objective function of the biomass model tries to maximise the returns to the landholder given the risk of production and the major constraint is that 100,000 green tonnes of biomass must be produced annually to supply the Integrated Tree Processing plant.

Returns can come from biomass production in terms of net present value as modelled earlier in this study (Figure 42), or from NRM credit payments from the government. Risk of biomass production (Figure 52) is also incorporated into the analysis by multiplying it by the NPV of returns to biomass to create an expected value of returns.

NRM credit payments at this stage are designed as a payment for ecosystem services offered by landholders. In this case, landholders can gain an NRM credit payment for salinity and wind erosion mitigation through revegetation for biomass. Salinity payments are equal to the present value of the total avoided costs of salinity to downstream users (Figure 16) resulting from revegetation of biomass species. Some work has been done quantifying the public cost of wind erosion in the Corridor (Williams and Young 1999). Williams and Young (1999) suggest that the public costs of wind erosion range between $1 Million and $56 Million per year and hence, are large enough to justify public investment in wind erosion mitigation. However, relating these estimates to the available wind erosion databases is difficult.

For the purposes of this study, a nominal credit system is developed based on the Wind Erosion Potential data in the PIRSA Soil Landscape Units database to test the likely impact of a wind erosion credit system. Revegetation of biomass species is considered to remove the wind erosion potential of a grid cell. PIRSA Wind erosion potential classes are given a cost score between 1 to 5 with 1 being high potential and 5 low potential (Figure 53). A payment of $20 is suggested per hectare per point of increase in Wind Erosion Potential cost score. Thus, if a grid cell is put into biomass production that has a Wind Erosion Potential cost score of 2 (Moderately High), revegetation for biomass production results in an increase of 3 cost score points to 5. Hence, the payment would be (5 – 2) x $20 x 6.4516 ha = $387.

The NRM credit system as used in this study is similar to a devolved grant scheme where landholders are paid extra to grow biomass in locations that result in the public benefits of reducing wind erosion potential and river salinity. The credit system can be developed at a later date to include a cap and trade system, but at this stage it simply involves payments for public benefits that help offset the costs of biomass production.

Layers in Objective Function		Constraint Layers	
Attribute	**Use**	**Attribute**	**Use**
Returns from biomass	Higher returns better	Biomass production	Minimum of 100,000 tonnes
Salinity credits	Higher returns better	Pre-European Vegetation Communities	No more than 85% of each class under biomass
Wind Erosion Potential	Higher returns better	Climate Zones	No more than 85% of each class under biomass
Risk of production	Lower risk better	Soil Land Systems	No more than 85% of each class under biomass

Table 30 – Description of the layers used in setting geographic priorities for revegetation for biodiversity in MCDA.

In the biomass model, each attribute layer in the objective function has dollars for units. The major constraint in the biomass model is that 100,000 green tonnes must be produced each year. Biomass Production (*BP*) information is modelled earlier in this study (Figure 36). Other constraint layers are similar to the representativeness targets used in the revegetation models formatted in a site x features matrix where each grid cell is a site and each constraint class (each Pre-European Vegetation Community, Climate Zone, and Soil Land System) is a feature. The elements of the matrix are given a binary digit (0 or 1) depending on whether the feature occurs at the site. The constraint ensures that biomass production does not preclude the opportunity to represent at least 15% of each feature by revegetation for biodiversity.

The optimisation problem for biomass production is formulated in a similar way to the revegetation for biodiversity problem. The number of grid cells (*m*) in the Corridor is 188,655. The total number of features (*n*) equals 92 as Long-Term Eroding Land is not considered and salinity benefits are included as a salinity credit system in the objective function. Thus, an *m* x *n* matrix **A** (188,655 rows (grid cells) x 92 columns (features)) was created whose elements a_{ij} are given a binary value according to the presence or absence of each feature (*j*) at each grid cell (*i*). Grid cells are given a value of one if it supports a particular feature, zero otherwise such that:

$$a_{ij} = \begin{cases} 1 \text{ if feature } j \text{ occurs at grid cell } i \\ 0 \text{ otherwise} \end{cases}$$

for $i = 1 \ldots m$ and $j = 1 \ldots n$

A second matrix **B** (188,655 rows x 2 columns) is also created which holds a land cover and a land tenure mask constraint. The constraints describe whether the cell is Dryland or not (*D*) and whether the grid cell is Private Land or not (*P*) or not. This information used to limit biomass production to dryland cells that are privately owned. Dryland areas are defined as areas within the Corridor that are not under remnant vegetation, nor irrigated, nor on the flood plain. The elements of **B**, b_{ik} are given a binary value according to the presence or absence of each particular mask constraint (*k*) at each grid cell (*i*). Grid cells are given a value of one if it supports a particular mask constraint, zero otherwise such that:

$$b_{ik} = \begin{cases} 1 \text{ if mask constraint } k \text{ occurs at grid cell } i \\ 0 \text{ otherwise} \end{cases}$$

for $i = 1 \ldots m$ and $k = D, P$

Next, a variable is defined that reflects whether or not a site is selected for biomass production, as the vector **X** with dimension *m* and elements x_i, given by:

$$x_i = \begin{cases} 1 \text{ if site } i \text{ is selected for biomass production} \\ 0 \text{ otherwise} \end{cases}$$

for $i = 1 \ldots m$

Where the biomass model differs to the previous models is that the objective function tries to maximise returns in real dollars rather than minimise an aggregate index. Returns are calculated by summing the expected value of biomass returns (or the product of biomass returns (*BR*) and risk (*R*)) with the returns from salinity credits (*S*) and wind erosion credits (*W*) all measured in units of dollars per grid cell. There are no criterion weights to adjust in this model because the units are all in dollars. However, the payment per wind erosion credit can be modified.

The objective function is then to:

maximise $\sum_{i=1}^{m} x_i (BR_i (1 - R_i) + S_i + W_i)$,

subject to the following constraints:

biomass production must be capped at 100,000 tonnes

$$\sum_{i=1}^{m} x_i (BP_i) \leq 100,000 \ ,$$

biomass production can only occur on dryland, privately owned land:

if $b_{iD} . b_{iP} = 0$, $x_i = 0$, for $i = 1,2,...,m$,

biomass production must not cover more than 85% of each Pre-European Vegetation Community, Soil Land System, and Climate Zone so that opportunities for revegetation of representative samples (15%) of each biophysical type for biodiversity are not precluded:

$$100 - \frac{\sum_{i=1}^{m} a_{ij} x_i}{\sum_{i=1}^{m} a_{ij}} \times 100 \geq 15 \text{ for } j = 1,2,\ldots,n,$$

where $a_{ij}, x_i \in \{0,1\}$

Four different models of biomass production are assessed. Model 1 is a straight profit maximising model which identifies grid cells for biomass production that yield 100,000 tonnes per year and have the highest net present value returns over 100 years. Model 2 also tries to maximise the profit but also ensures that biomass production does not preclude the ability to represent 15% of each biophysical feature through revegetation. Model 3 extends Model 2 and includes consideration of the risk involved in biomass production and attempts to maximise the expected value of returns (returns x risk). Finally, Model 4 extends Model 3 and includes not only expected returns from biomass but also the returns from salinity and wind erosion credits. The four models are summarised below:

Model 1 – Maximise returns from biomass industries

Model 2 - Maximise returns from biomass industries, do not preclude revegetation options for biodiversity

Model 3 - Maximise expected returns from biomass industries, do not preclude revegetation options for biodiversity

Model 4 - Maximise expected returns from biomass industries, salinity and wind erosion credits, do not preclude revegetation options for biodiversity

5.4.3.2 Results

The biomass models identify the areas that yield the highest returns from biomass production and from credits paid to landholders for public salinity and wind erosion benefits. The biomass models identify sites from a purely rationalist viewpoint and the selected sites are those that have the highest economic returns. Net returns considers the opportunity costs of existing land uses and so in these models the sites are largely concentrated in areas of minimal use and sheep grazing land as these have the lowest opportunity costs. Model outputs are designed to give an idea of the economic viability of a biomass industry in the Corridor given an ITP plant at Kingston-on-Murray. The precise network of sites identified by the models would rarely ever be converted to biomass due to other unmodelled socio-economic factors operating including farmers attitude to risk and imperfect information. In all solutions there is a good amount of flexibility. Whilst the first optimal solution is presented in this study there are likely very many optimal solutions which differ from the one presented minimally. Further, there is likely to be very many slightly sub-optimal solutions which are only slightly worse than the optimal solution presented here.

Each model identifies a network of grid cells the sum of whose total production of green biomass is very close to 100,000 tonnes per year on the second and subsequent harvests (Figure 36). All 4 model outputs were very similar. Model 1 just found the sites that yielded 100,000 tonnes of biomass at the highest NPV returns from biomass production only. A total of 14,215 ha of land is identified in Model 1 for biomass production returning a NPV of just over $24 Million. Although salinity and wind erosion were not used to influence site selection in this model, the total NRM credits that would be earned is $584,576 in salinity credits and $364,046 in wind erosion credits. At 35.9%, the mean risk percentage of grid cells is fairly low even though risk was not considered in the model (Table 31).

Grid cells selected for biomass production in Model 1 (and Models 2 and 3) occur mainly in spatially contiguous zones and tend to occur adjacent to irrigated areas and the flood plain. Essentially, this is because these areas have been mapped as minimal use by DWLBC and therefore were given a low opportunity cost in this study. A finer scale assessment of these areas is required to verify this land use.

Locating biomass amongst irrigated areas may have secondary advantages both for biomass production and salinity. Production of biomass adjacent to existing irrigation areas may be able to take up or *mine* water from the soil profile and from water tables raised by irrigation. This has the potential to increase biomass production significantly. In addition, the take-up of water from the soil profile and the lowering of water tables by biomass production reduces problems of water logging and land salinisation. It will also reduce the impact of irrigation in forcing saline groundwater into the River Murray and reduce river salinity. Thus, whilst these sites offer the most profitable options for biomass, these locations may also have the dual effect of increasing production through soil water mining and have the greatest benefits for natural resource management in reducing land and river salinity. Biomass production in these areas seems to be a commercially viable and attractive option.

Post Planning Indicators	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Total green tonnes of biomass	100,000	100,000	100,000	100,000
Total area of biomass production	14,215 ha	14,215 ha	14,069 ha	14,122 ha
Net present value of biomass production	$24,091,700	$24,091,700	$23,942,330	$23,950,330
Total salinity credits	$584,576	$584,576	$569,732	$567,386
Total wind erosion credits	$364,046	$364,046	$355,979	$369,669
Total economic benefits	$25,040,322	$25,040,322	$24,868,041	$24,887,385
Mean risk of biomass production	35.9%	35.9%	35.2%	35.3%

Table 31 – Post planning indicators of the five revegetation models assessed in this study.

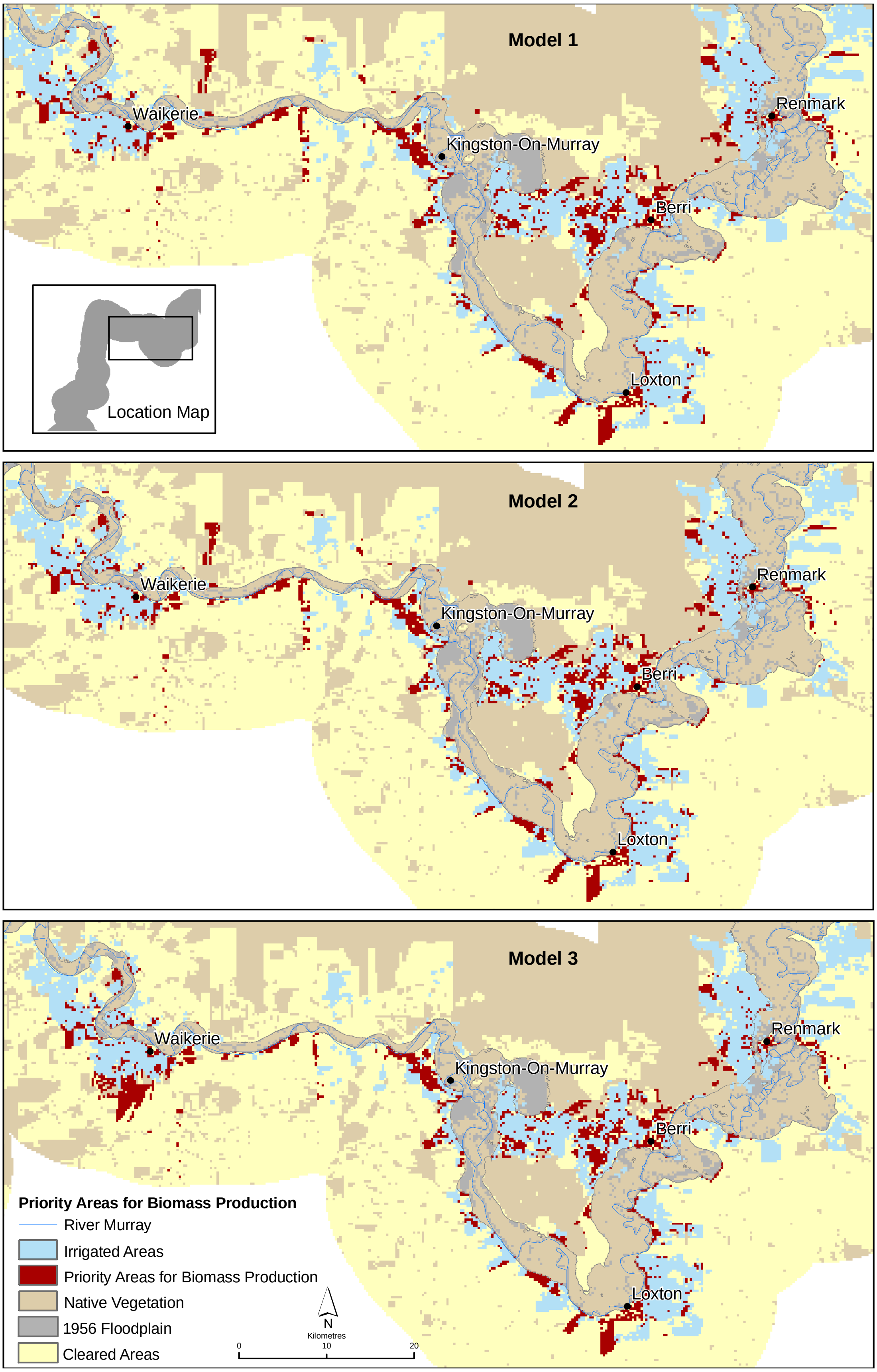

Figure 60 – Geographic priorities for biomass production concentrated in the north-east of the Corridor identified by Models 1-3.

Model 2 extends Model 1 to include the biodiversity constraint of not precluding the revegetation of 15% of each Soil Land System, Pre-European Vegetation type and Climate Zone. It is apparent that Model 1 does not preclude this biodiversity target anyway so the results for Model 2 are the same as Model 1. Biomass production only covers a low proportion of the area of most features (Table 32). This biodiversity constraint is not so important for small areas of biomass production but may be important if larger areas are to be considered (i.e. 2 or more ITP plants).

Feature	Model 1	Model 4	Feature	Model 1	Model 4
Soil Land Systems			**Soil Land Systems**		
164	100	100	568	100	100
211	100	100	578	100	100
288	100	100	579	100	100
297	100	100	594	100	100
298	100	100	598	100	100
316	96.15	96.475	599	100	100
317	100	100	600	100	100
319	98.597	99.643	603	100	100
320	100	100	604	100	100
326	100	100	610	100	100
327	100	100	615	100	100
336	99.222	99.222	616	100	100
340	100	100	618	100	100
342	100	100	-9999	100	100
344	97.6	96.618	**Climate Domains**		
345	96.788	97.001	1	99.501	99.522
351	100	100	2	100	100
361	99.553	99.911	4	98.108	98.079
371	79.838	79.838	6	100	100
388	100	100	7	95.127	100
394	100	100	10	100	100
422	100	100	11	100	100
444	100	100	12	25	100
466	100	100	**Pre-European Vegetation Community**		
477	100	100	101	100	100
482	97.008	100	1101	100	100
486	100	100	1201	98.303	98.303
487	100	100	1401	99.878	99.878
489	100	100	1701	33.333	33.333
493	100	100	1801	98.117	97.82
499	100	100	1901	100	100
503	100	100	201	100	100
507	100	100	2802	100	100
509	100	100	3101	100	100
514	98.841	100	3301	99.279	99.279
515	100	100	3601	100	100
516	100	100	3701	100	100
522	100	100	3801	98.817	99.004
525	100	100	4001	99.631	99.631
527	100	100	4601	100	100
533	100	100	4701	98.661	97.448
534	100	100	5001	100	100
536	100	100	5101	100	100
545	100	100	601	85.366	85.366
556	100	100	801	97.52	97.913
557	100	100	901	100	100
564	100	100	Unknown	99.04	99.17

Table 32 – Proportions (%) of Pre-European Vegetation Communities, Climate Domains and Soil Land Systems not covered by biomass production for Model 1 and Model 4 and therefore able to be represented by native vegetation. Model 4 has the biodiversity constraint but it has little effect as the straight profit maximising Model 1 does not preclude options for revegetation for biodiversity in the Corridor.

Model 3 extends Model 2 to consider the risk of biomass production using the expected value of returns (returns x risk). Risk is derived from simulation and effectively represents the proportion of simulation runs for which the biomass economic model yields a negative net present value return. The area selected for biomass production is slightly less than Model 2 at 14,069 ha. In this model a trade-off is made between the total NPV returns and the risk of those returns. Hence, whilst the mean risk is slightly reduced compared to Model 2, so are the total NPV and the returns from salinity and wind erosion credits. The inclusion of the risk component in the model does not affect the selection of grid cells greatly and the mean risk is reduced by less than 1 percent. The influence of risk on the selection of land could be emphasized by weighting it more heavily if the attitudes of farmers to biomass production in the Corridor were more risk averse.

Model 4 extends Model 3 insofar as it selects cells that maximise returns not only from biomass production but also from salinity and wind erosion credits. The level of credit payment used in this study involves for salinity credits to landholders is equivalent to the present value of the downstream costs of river salinity avoided by revegetation of biomass. For wind erosion, credits involve the payment of $20 per index point per hectare. Maximising not only the returns from biomass but also NRM credits results in a slight increase in the area required for production, a slight increase in the returns from biomass and from wind erosion credits, and a slight decrease in both salinity credits and mean risk. Thus, compared to Model 3 there is a slight increase in the total returns from biomass and credits combined and the trade-off is a slight increase in risk.

Again, the spatial location of biomass production identified in Model 4 suggests that the best locations are those with the lowest opportunity costs and within close proximity of the ITP plant at Kingston-on-Murray. Assessment of these areas using high-resolution aerial photography reveals mixed results, mainly related to the scale of the data used in the analysis. In many locations Model 4 selects cells than are very suitable for biomass production as they are cleared and do not appear to be supporting agriculture. However, there are also a few problems. Many sites that are selected include irrigated land that is temporarily out of production and hence was not mapped as irrigated in the 2003 DEH irrigation mapping or classified as irrigated agriculture in the DCDB. Also, many sites are selected that appear to support degraded remnant vegetation. These sites have not been mapped as remnant vegetation by DEH and so they are available for selection in the models. It would not be possible or desirable either economically or ecologically to clear this land to plant biomass species. The basic planning principle though has been distilled. Specifically, biomass has the potential to be profitable in the Corridor and should be planted in areas that have low opportunity costs and minimal use, close to the ITP plant, and preferably, interspersing irrigated areas.

The models have identified at the regional scale the most profitable grid cells for biomass production and have found that biomass production in the Corridor in the best possible sites is worth about $24 Million more than current land use. Revegetation of biomass in the most profitable grid cells has some natural resource management benefits and the inclusion of market-based policy instruments like credits are fairly expensive (in the order of $1 Million) and have very little impact on the total amount of public NRM benefits.

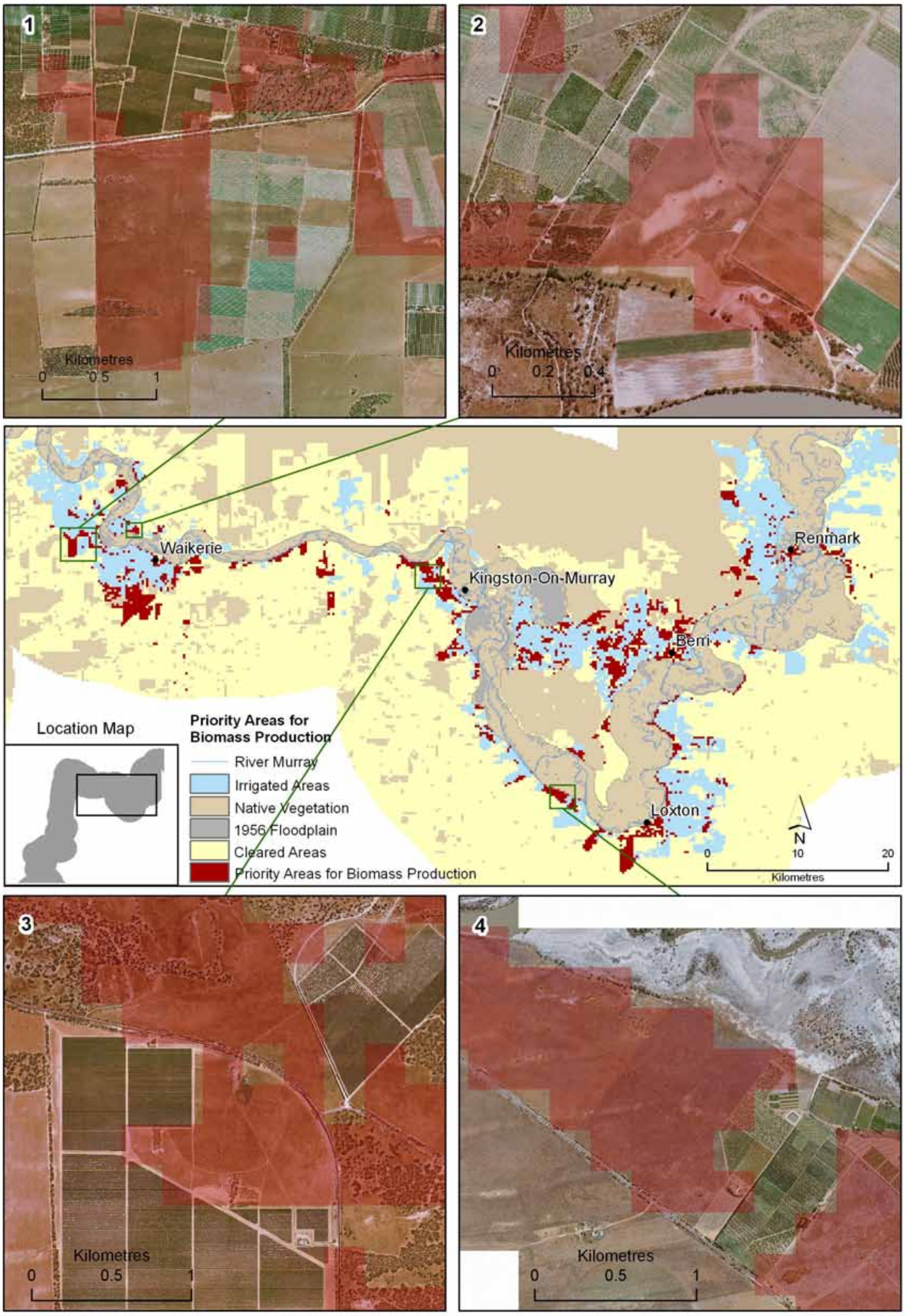

Figure 61 – Geographic priorities for biomass production in the Corridor identified by Model 4. Sites identified in Inset 1 are mostly suitable except some areas of native vegetation and a golf course. Inset 2 displays sites that are again mostly suitable but also some irrigated land not classified as irrigated in the Crops2003 database. Inset 3 displays sites selected that are mostly suitable but includes some native vegetation not mapped as such by DEH. Inset 4 displays sites selected adjacent to an irrigated area and on the edge of the flood plain which would be very beneficial for salinity mitigation.

6. Key Findings and Policy Implications

6.1. Salinity

6.1.1 Key Findings

- The total salinity contribution from the dryland areas of the Corridor in 100 years has been estimated to be around 30 EC at Morgan (Barnett and Yan 2004). However, the salinity benefits achieved through revegetation as modelled by SIMPACT over a 100 year time frame is 1.96 EC at Morgan after 50 years and 4.14 EC at Morgan. This is considered to be a conservative estimate and research is required to improve this estimate.
- Based on these estimates the total cost to downstream users of river salinity avoided by revegetation in the dryland areas of the Corridor is just over $3.15 Million in present value terms over 100 years.
- Most of the salinity benefits can be achieved by revegetating an area of 10,000 ha.

6.1.2 Policy Implications

The modelled river salinity benefits and the associated costs to downstream users avoided by revegetation in the dryland areas of the Corridor are low. They also occur well into the future and hence, are heavily discounted in economic analyses. Conversely, the costs involved in revegetation and the opportunity costs are high and immediate. Hence, based on these estimates, the implementation of a scheme that encourages revegetation for salinity alone is not a cost effective policy option for the Corridor. The integration of salinity credits into integrated NRM policies could however, complement other incentives for landholders to undertake NRM actions. The cost of salinity to downstream users may provide a suitable guide as to the appropriate level of payment for salinity credits in the Corridor.

Salinity mitigation has potential to be an economic driver of NRM actions in the Corridor. More accurate estimates of the salinity benefit of revegetation are required. Revegetation policy for salinity benefits needs to be specifically targeted to encourage revegetation in the high salinity benefit areas.

6.2. Biomass

6.2.1 Key Findings

- Biomass production for supplying an Integrated Tree Processing (ITP) plant is very likely to be as profitable as, or more profitable than, existing agriculture in the Corridor. Under the Most Likely Scenario (time frame of 100 years and discount rate of 7%) the total net present value of biomass production for each 6.4 ha grid cell ranges between $5,000 less, to $25,000 more, than returns from existing agriculture with an average NPV of $7,168. The Modified Internal Rate of Return ranges between 6.8% and 7.7% and the Equal Annual Equivalent payments range from -$54 to $271 per year per grid cell or -$8.37/ha/yr to $42/ha/yr. The total potentially viable area for biomass production is 625,231 ha or 99.6% of the dryland area of the Corridor. The potential tonnage of green biomass supplied by the economically viable area (490 million tonnes per annum) far exceeds the production required to supply an ITP plant (100,000 tonnes per annum).

- The most profitable locations for biomass production were found to be interspersed with existing irrigation areas. Biomass production in these areas may also have synergistic salinity benefits in lowering water tables and reducing recharge whilst at the same time increasing biomass production through soil water mining. The synergies between biomass and irrigation in the Corridor should be investigated further.
- Cash flow is a problem for production of biomass as farmers do not register a positive cash flow for at least 7 years. Biomass production may take much longer than this to return a positive net cash flow for the farmer depending on site characteristics.
- Sensitivity analysis shows that no parts of the Corridor are profitable under all possible parameter values. Under average conditions many parts of the Corridor are viable for biomass production but some are not. An optimistic view of biomass production which assumes low costs and high prices and productivities would state that all areas have the potential to be viable and some areas have the potential to be considerably more profitable than existing agriculture.
- The factory gate price of biomass is the single most important factor affecting the profitability of biomass production in the Corridor.
- Conservatively, a robust supply of >100,000 tonnes of biomass per year can be expected when the factory gate price of biomass exceeds $35 per green tonne. At this price biomass production becomes more profitable than current agriculture over a large enough area to produce a supply of > 100,000 tonnes.

6.2.2 Policy Implications

Biomass production is probably viable as a stand alone economic exercise in the Corridor. However, establishment of a viable biomass industry involves much more than demonstrating its potential viability. To achieve a viable biomass industry in the Corridor, an Integrated Tree Processing plant has to be established and landholders have to be contracted to grow biomass. These steps will require significant industry development initiative to be taken, either by the SA government or other relevant agencies such as the Regional Development Board. There are several ways forward for establishing a biomass industry including private contractual arrangements with the commercial sector (e.g. energy companies) and landholders, farmers co-operatives and other models.

Carbon sequestration and trading also looms as another potential driver of a biomass industry in the Corridor and elsewhere in SA for that matter. In addition, the additional income generated from a potential involvement in carbon trading would significantly increase the profitability of biomass. An issue to be overcome however, is the cash flow problem. Contractual arrangements may need to be established that provide a regular payment to landholders such as the Equal Annual Equivalent payment.

Based on recent modelling, the salinity and wind erosion benefits of biomass in particular mitigation, have been shown to be somewhat less than expected. However, the NRM benefits are significant and may justify the effort and expenditure required to establish a biomass industry. The larger the area of biomass production the greater the NRM benefits. Market research is required to quantify the market for biomass products such as renewable energy. Economies of scale may quickly be achieved for NRM benefits if the market for biomass products would support more than one ITP plant in the Corridor. Once the initial industry development work has been done the industry should prove to be viable on its own and contribute significant public NRM benefits. For a single plant the cost-benefit of establishing a biomass industry is fairly equivocal but for more than one plant the NRM benefits may justify industry development if the market is there for the ITP products.

6.3. Wind Erosion

6.3.1 Key Findings

- The total area of long-term eroding land in the Corridor is 312 ha.
- The total area of soils with a wind erosion potential of moderately high to high is 40,000 hectares or 4% of the study area.

6.3.2 Policy Implications

Wind erosion is a significant NRM problem in the Corridor with substantial public costs. However, public wind erosion benefits do not provide sufficient incentive to drive private investment in NRM actions. Wind erosion benefits could be integrated into a broader public NRM policy in the Corridor. Policy incentives for addressing wind erosion would also need to be specifically targeted at high priority sites.

6.4. Carbon

6.4.1 Key Findings

- Given recent empirical productivity estimates, trading the carbon produced by revegetation in the Corridor could produce annual returns between $50 and $105 per hectare which is comparable to current agriculture.
- It is possible that vegetation management activities could attract carbon credits.
- Revegetation of local native species for biodiversity is ideally suited for carbon trading and the restored native community not only has multiple NRM benefits but an income may also be generated from carbon trading.
- Revegetation of fodder crops such as saltbush is unlikely to attract significant carbon credits because of the low productivity of the species.
- Biomass species are also suited for attracting carbon credits and there may be 2 options for carbon accounting of biomass species. Although they are harvested periodically and burned the carbon stored in the woody lignotuber may be counted. The other option is that the carbon emissions avoided by producing clean electricity may be counted. This is around $1,375,000 per annum in carbon credits at today's prices from a single 5MW ITP plant.

6.4.2 Policy Implications

The carbon market is developing rapidly. Initial estimates suggest that current carbon trading prices are sufficient to provide farmers a viable income source to support revegetation and possibly vegetation management in the Corridor. Market-based policy may involve either integrating carbon credits within other NRM schemes or creating a stand alone carbon program similar to the Victorian CarbonTender program.

Although the current economic returns from carbon trading in the Corridor may potentially be economically viable, barriers to trade from Australia's non-participation in the Kyoto protocol and market uncertainty obstruct the widespread land use change in the Corridor. If these can be overcome, carbon trading has the potential to provide additional incentives for participation in other programs such as biomass production. Carbon trading may also have the potential to become a stand alone economic driver for widespread land use change.

Carbon provides an ideal incentive for encouraging the revegetation and restoration of native habitat which has NRM benefits for biodiversity, salinity and wind erosion.

Any stand alone carbon trading program needs to offset both the cash flow problem and the uncertainty involved in the carbon market. This can be done by tendering for carbon contracts where the government pays the landholder upfront for the first few years carbon production which may be paid back by the landholder from selling the carbon at a later date on the market. After that the landholder is free to trade the carbon on the open market. This involves some risk to both parties and speculation on the price of carbon.

6.5. Vegetation Management for Biodiversity

6.5.1 Key Findings

- Over 25% of remnant vegetation on private land is already managed. Meeting the NRM resource condition targets of managing 50% of remnant vegetation on private land will require a doubling of the existing managed area of remnant vegetation on private land - an increase of 99,751 ha.
- The distribution of current protected/managed areas of remnant vegetation is not representative of the range of biological and physical environments of the Corridor.
- The establishment costs of meeting the resource condition target for vegetation management range from $49 Million to $300 Million.
- The least expensive way of meeting regional resource condition targets for vegetation management has a total annual opportunity cost of $1,204,297 although the biodiversity and NRM benefits of this solution are poor.
- Including representativeness targets in vegetation management (i.e. ensuring at least 50% of each Vegetation Community, Climate Zone and Significant Species Habitat is managed) has an additional opportunity cost of only $84,000 per year (7%). The benefits for biodiversity of including these targets are likely to be substantially greater as will the effectiveness of vegetation management efforts in conserving biodiversity.
- Including the NRM targets in vegetation management (i.e. managing all remnant vegetation on Long-Term Eroding Land and Salinity Benefit Areas) has negligible extra biophysical or economic cost.
- Significant improvements in the Area, Shape, Fragmentation, Habitat Quality, and Wind Erosion Potential of managed areas of remnant vegetation can be achieved for minimal extra opportunity cost of only $40,000 per year (3% increase)

6.5.2 Policy Implications

The establishment costs and opportunity costs of implementing resource condition targets in the Corridor are high compared to current government funding. Sufficient funding to encourage vegetation management on the scale required to achieve regional resource condition targets is unlikely to become available in the foreseeable future.

Hence, if vegetation management is to occur on a scale commensurate with resource condition targets there will need to be significant costs borne by private landholders. Market-based policy is required to have any chance of reaching regional NRM targets for vegetation management.

Systematic regional planning can increase the biodiversity and NRM benefits of vegetation management actions at only marginal extra cost. Sites funded for vegetation management actions need to be highly spatially targeted for optimal NRM benefit and cost effectiveness.

The shape of many areas selected in the spatial optimisation models is often complex and impractical for implementing vegetation management. Policy options need to be flexible and iterative to cope with the preferences of landholders for locating vegetation management actions on the ground whilst still working toward the most cost effective solution identified in the models.

6.6. Revegetation for Biodiversity

6.6.1 Key Findings

- The minimum opportunity cost involved in increasing remnant native vegetation by 1% in the Corridor is $41,685 per year and requires an area of revegetation of 5,107 ha. The establishment costs of reaching the 1% revegetation target ranges between $2.5 and $15 Million. The most cost effective sites for revegetation would have minimal benefits for biodiversity and NRM and undertaking revegetation in these locations would not be a cost-effective use of NRM resources.
- Implementation of a 15% representativeness target in the Corridor (i.e. ensure at least 15% of each Pre-European Vegetation Community, Climate Zone and Soil Land System are represented by either remnant vegetation or revegetation) has a significantly higher opportunity cost of $706,000 per annum, requires 4 times the area of the 1% target (21,578 ha) and the establishment costs range between $13.8 and $83 Million. However, the resulting geographic priorities for revegetation have a much better chance of conserving regional biodiversity.
- Further spatial enhancement of the biodiversity and NRM benefits of revegetation by including Landscape Context, Fragmentation and Wind Erosion Potential costs) involves an increase in opportunity costs of nearly $150,000 per annum (a 21% increase).
- Including the NRM benefits of revegetating all Long-Term Eroding Land and Salinity Benefit Areas (not irrigated) requires an extra 6,000 ha of revegetation and around $215,000 per annum extra opportunity costs. The opportunity and establishment costs of revegetation to achieve wind erosion and salinity benefits are likely to be many times higher than the public benefits from reductions in these NRM benefits.
- The spatial distribution of areas for revegetation are a mix of new patches, infill of existing remnants, stepping stone patches and linking areas.

6.6.2 Policy Implications

- Current levels of funding for revegetation is unlikely to achieve the scale of revegetation required to achieve regional biodiversity targets. If the stated resource condition target of achieving a 1% increase in vegetation and the additional 15% representativeness target are to be met, significant costs must be borne by private landholders. Market-based policy mechanisms may greatly enhance the likelihood that these revegetation goals are met.
- Sites funded for revegetation actions need to be spatially targeted for optimal NRM benefit. The sites selected for short term funding should coincide with the high priority sites identified for meeting the long term 15% representativeness target.

- It is prudent to include Landscape Context, Fragmentation and Wind Erosion Potential in enhancing the location of revegetation for biodiversity, as the enhanced likelihood of success of revegetation in these priority locations and the increase in biodiversity benefits is likely to be cost effective.
- Including the NRM objectives of Salinity Benefit Areas and Long-Term Eroding Land in setting priorities for revegetation is very expensive and the costs far outweigh the benefits of revegetating these areas for biodiversity based on the parameters used in this study.

6.7. Revegetation for Biomass

6.7.1 Key Findings

- The network of sites that yield 100,000 tonnes of biomass at the highest NPV returns from biomass production include a total of 14,215 ha of land and return a NPV of just over $24 Million more than current land use (over a time frame of 100 years and discount rate of 7%). This estimate of profitability is however, likely to be conservative given the latest estimates of biomass species productivity in the Corridor (Hobbs and Bennell 2005). The spin-off salinity benefits total $584,576 in avoided costs to downstream users and wind erosion benefits total $364,046 in credits given the potential payment system developed in this study. The economic risk of these higher profit sites is fairly low.
- The most economic sites for biomass production occur mainly in spatially contiguous zones and tend to occur adjacent to irrigated areas and the flood plain. This is because these areas tend to be classified as minimal use land and hence are given a low opportunity cost. Biomass production in areas interspersing irrigated areas may have synergistic benefits whereby production is increased and raised water tables may be decreased.
- The most economic sites for biomass production for supplying 100,000 tonnes for a single Integrated Tree Processing plant do not preclude the implementation of biodiversity goals in the Corridor. However, the impact of biomass production on biodiversity may need further investigation if production is required to supply 2 or more ITP plants.
- Depending on landholder attitudes to risk, the returns to biomass production can be traded-off for increased certainty in production using the expected value of returns.
- The inclusion of market-based policy instruments like payments in the form of credits for public benefits of salinity and wind erosion mitigation will cost in the order of $1 Million in public funds and have only a minor impact on the total amount of public NRM benefits.

6.7.2 Policy Implications

- Experience from Western Australia suggests that the location of biomass production adjacent to cereal crops may reduce elevated water tables and provide the NRM benefit of mitigating dryland salinity. As a corollary, locating biomass production adjacent to irrigated areas in the Corridor may have similar salinity benefits in reducing land and river salinity.
- Thus, the NRM benefits of biomass production including salinity, wind erosion and potentially carbon, adds significant weight to investment in establishing a biomass

industry in the Corridor. Biomass production seems to be a fairly attractive option with dual economic and environmental benefits.

- The establishment of biomass production not only represents an economic driver for private parties motivated by profit, but also yields significant public NRM benefits. However, the adoption of a credit scheme involving payments for NRM benefits such as salinity and wind erosion mitigation is expensive and does little to increase NRM benefits.

7. Policy Options and Design

A range of policy options exist to encourage large-scale vegetation management and revegetation including auction- or tender-based grant systems, credit systems, and biomass-based industry development. The policy options are required to provide incentives for large scale natural resource management actions that provide the multiple objective NRM benefits of salinity, biodiversity, wind erosion and carbon benefits (Connor and Bryan 2005). None of these policy options alone could feasibly facilitate the scale of revegetation and vegetation management required to meet multi-objective INRM resource condition targets in the Corridor. The best potential for achieving the targets is a multi-faceted policy mix involving the best elements from a variety of different policy options and tailored specifically to the different types of revegetation and vegetation management in the River Murray Corridor.

7.1. Invited Tender for NRM Contracts

- Invited tender for NRM contracts involves an auction design where tenders are specifically invited for vegetation management and revegetation contracts from landholders and community groups which propose action in high priority areas. This will facilitate the high degree of spatial targeting required to address high priority sites for NRM
- Tendering approaches may be applied to individual landholders, Local Action Planning (LAP) groups, or larger investors willing to negotiate on behalf of landholders
- Tenders should be invited from all landholders and groups with influence over high priority sites. However, prioritisation reduces market size and caution is required to avoid problems arising from thin markets
- Bids may be submitted that propose either the revegetation of local native species for biodiversity, or the management of remnant vegetation. There should be 2 classes of bids which are evaluated separately – revegetation and vegetation management.
- Differentiation in tender selection can be done based on the NRM benefits offered per dollar and the tenders offering the most cost effective actions selected for funding. Essentially, tenders offering revegetation and vegetation management over the largest area in high priority locations are a high priority for funding
- A reserve price may be set that specifies the maximum that will be paid per hectare of NRM action
- One advantage of this approach is that the maximum expenditure by the government will be known
- This approach is likely to increase the cost effectiveness of government money spent on revegetation, particularly for biodiversity. Our experience (Bryan *et al*. 2004a) suggests that around twice the environmental benefits can be gained from NRM funding using a tendering approach
- Tendering approaches have the advantage of requiring little institutional change. A tendering approach simply adds value to existing devolved grant schemes. In addition, the existing institutional infrastructure is already in place. All funded NRM actions should involve putting a management agreement or Heritage Agreement on sites proposed for NRM action
- Tendering approaches for individual landholders and groups are particularly suited to the less economic local native species plantings required for biodiversity goals. Whilst

tendering approaches could also be applied to encourage other types of NRM actions such as revegetation such as fodder crops and woodlots, the NRM benefits of these types of revegetation are limited and funding spent on these efforts may be better spent of high priority actions with multiple NRM benefits in high priority sites.

- Established techniques and appropriate data for tender ranking and selection are available (Bryan *et al*. 2004a)
- Significant investment is required to get the auction scheme off the ground as the responsibility for the design of revegetation projects is devolved to the landholders and substantial information is required upfront to support their bid
- A key to the success of tendering schemes in NRM is the supply of adequate information to landholders to support their bid
- Capital, time preference and information constraints would likely be more significant for a tendering policy focussed on individual smaller enterprises rather than larger institutional investors
- Capital and information constraints may be overcome by offering contracts with evenly spread annual payments. This may also increase certainty on behalf of the funding agency as payments are made contingent upon performance.
- The tendering system needs to be ongoing. Priorities for NRM action can be recalculated and updated each round. This iterative approach enables consideration of the NRM impacts expected from the projects funded in the previous round and an assessment of how these change future geographic priorities. This iterative approach can also integrate new information affecting geographic priorities as this becomes available. Tools can be developed to support this (Bryan *et al*. 2004b).

7.2. NRM Credits

- An NRM credit system (Ward and Connor 2004, Willis and Johnson 2004) could be integrated with the tendering system suggested above. Credit systems can be set up as a straight payment to landholders for actions that achieve NRM benefits initially, with a cap and trade system potentially implemented at a later date.
- Salinity credits could include payments for revegetation that reduces the cost of future salt loads to the River Murray. A well developed technical capacity is established to assess salinity impacts of revegetation and dollar benefits to downstream users. However, there is some risk due to the uncertainty surrounding the effectiveness of revegetation in reducing salt loading over time. To alleviate this, risk management could involve setting an upper bound on payments for revegetation at some fraction of the estimated cost of salinity to downstream users (e.g. 50%).
- A salinity credit scheme may be extended to a broader-focussed NRM (or Ecosystem Services) credit system where landholders receive payments for improving biodiversity or reducing wind erosion. However, there is significantly more risk attached to the extended credit system as measurement of the value of benefits to wind erosion and biodiversity is more difficult.
- A credit system involving government payments to landholders and groups for addressing the multiple objective resource condition targets of salinity, wind erosion and biodiversity may encourage some NRM actions. However, given the level of government funding likely to be available in the foreseeable future and typical levels of costs borne by landholders, an NRM credit system consisting of payments for salinity, wind erosion and biodiversity benefits is unlikely to encourage the scale of

actions required to achieve resource condition targets. Additional economic drivers are required to facilitate NRM action on this scale.

- The potential of carbon trading as an economic driver for achieving large scale NRM actions in the Corridor is considerable. Thus, whilst a detailed assessment of the economic potential of carbon sequestration in the Corridor is required, initial calculations based on the latest production estimates and price figures suggest that landholders may make an income from carbon trading comparable with existing agriculture. Carbon credits may also be integrated with salinity, biodiversity and wind erosion credits. NRM actions such as vegetation management and revegetation of local native species can have multiple objective salinity, biodiversity, wind erosion and carbon benefits. A policy mix involving salinity, biodiversity, wind erosion and carbon credits may provide a combined income from these sources may have the potential to encourage the scale of NRM actions required to meet resource condition targets.
- The fact that the Commonwealth has not ratified the Kyoto protocol has not dissuaded other states from initiating programs focussing on carbon trading. Victoria's CarbonTender program combines a tendering system for revegetation for biodiversity like the one outlined above with the future option of selling carbon credits earned from revegetation efforts on the global market.
- Before a multiple NRM benefit credit system could be implemented, research would be required to fully develop standard and accounting frameworks for quantifying appropriate credit payment levels for biodiversity and wind erosion mitigation and carbon sequestration actions. This should build on existing work quantifying the value of biodiversity (Hatton MacDonald and Morrison 2005), wind erosion (Williams and Young 1999) and the extensive literature and standards for carbon sequestration and trading.

7.3. Biomass Industry Development

- A biomass industry in the corridor is likely to be profitable as a private enterprise and can result in considerable NRM benefits at minimal government expense. An industry development policy may hasten the uptake of the opportunity.
- This policy option involves putting out to tender a single biomass industry contract which involves managing the complete operations of a biomass industry plant in the Corridor as a commercial enterprise including the local production, processing and marketing of biomass products. Industry development may also involve market research and local extension work. It is not envisaged that biomass industry development will be expensive.
- Tendering approaches involving larger investors may be best aimed at utility-type companies looking to run a biomass processing plant and contract local landholders to revegetate for biomass industries. However, a farmer co-operative type model may also be a possibility.
- This kind of model is widely used in forestry contracts and a similar model is used in the context of biomass production in Western Australia.
- A private enterprise model achieves economies of scale as all of the processes from production to market are managed by a private company
- Much of the risk involved in the biomass industry is borne by the company rather than the public

- For a biomass industry model to be successful, cash flow timing constraints that make perennial plantings unattractive to landholders would have to be addressed. Contracts guaranteeing fixed annual payments may be required to encourage adoption of perennial woody species. This would be the responsibility of the company.
- Extra payments for NRM benefits such as salinity and wind erosion credits may not result in cost-effective additional NRM benefits. However, the market may support 2 or more ITP plants which will increase the NRM benefits of a biomass industry. Market research should include a quantitative investigation into the size of the market for biomass products in the Corridor.

7.4. A Policy Mix for NRM

As mentioned above, no single policy is likely to encourage the scale of NRM actions required to meet resource condition targets in the Corridor. The three options discussed above used together, may have the potential to achieve multiple objective NRM targets. The biomass industry development option has potential to encourage large scale revegetation of biomass species. This is a low cost option for government as biomass seems to be an economically viable exercise in the Corridor. Biomass plantings motivated solely by profit can also provide considerable salinity and wind erosion benefits. However, biomass production does not offer significant biodiversity benefits. The tendering system for NRM contracts has the potential to encourage some NRM actions, especially those contributing biodiversity benefits such as vegetation management and revegetation of local native species. The NRM credit payment system though, which includes payments for salinity, biodiversity, wind erosion and carbon credits, has the greatest potential to encourage cost effective, large scale, multiple objective NRM actions. Overcoming the barriers to carbon trading is the key precursor to the success of this policy option.

8. Directions for Future Research

8.1. Extending Systematic Regional Planning

Many of the biophysical processes modelled in this study, especially ecological processes, operate over entire regions. Systematic regional planning for NRM in the Corridor needs to be extended to take a whole-of-region approach for the Murray Darling Depression (MDD) bioregion.

Taking bioregional approach also involves integrating the different targets specified in the regional NRM planning of the four NRM groups/Catchment Management agencies occurring in the MDD. The targets addressed by SRP in the bioregion should also be extended from the limited set of NRM targets addressed in this study.

In addition to extending the analysis to the bioregion, quantification and modelling of the various attributes used as input into the model can also be enhanced. Biodiversity modelling can be improved using additional datasets. Salinity modelling needs to be improved to capture more accurately the impact of revegetation in mitigating river salinity. A model quantifying the economic potential of carbon trading across the region needs to be developed and a model of the social impacts of large scale NRM actions will enable the generation of socially resilient policy options.

8.2. Systematic Planning for NRM under Climate Change

Climate change presents a major challenge to the continued biophysical, economic and social viability of the region. Planning for NRM needs to identify options that provide the greatest biophysical benefits and maximise the resilience to climate change of regional biophysical, economic and social systems.

The spatial distribution of the impacts of climate change on rainfall, temperature and carbon dioxide in the region need to be modelled including the uncertainty involved in climate change impacts. Quantification of the risk and uncertainty surrounding each of the modelled attribute layers with respect to the impacts of climate change is required. Systematic regional planning needs to incorporate consideration of climate change and to identify geographic priorities for NRM actions that enable the most cost effective and the most resilient biophysical, economic and social outcomes.

8.3. Linking Systematic Planning with Real Outcomes

In this project we identified the high priority locations for revegetation to achieve multi-objective NRM targets based on the assumption that landholders act as fully informed, rational, profit maximisers. However, literature-based insights and experimental results indicate that this is rarely the case. Hence, further research required is to identify the mix and sequencing of policy instruments that best motivates landholders to undertake revegetation in high priority NRM areas.

This may be achieved through using an optimal policy design framework which links experimental economics with the systematic regional planning framework developed in this project. This would involve quantifying the real world behaviour and reactions of landholders to policy changes in an experimental economics setting. These behaviours can then be extrapolated to the region to assess the likelihood of reaching NRM targets under each policy scenario. This information may then be used to iteratively adjust the policy instruments to arrive at the policy scenario most likely to achieve regional NRM targets.

9. Conclusion

Natural resource management requires intensive and expensive actions over a large scale by private landholders largely for public benefit. The incentives for this to occur do not currently exist within the existing NRM policy framework. For NRM actions to occur on a scale that redresses regional threatening processes such as biodiversity decline, river salinity and wind erosion two things need to occur. Firstly, NRM actions need to be systematically planned so that multiple NRM objectives can be met most cost effectively. Secondly, policy is required that encourages these NRM actions in priority areas by providing the right incentives.

In this study we have developed the concept of systematic regional planning (SRP) for multiple objective natural resource management and present a full implementation in the South Australian River Murray Corridor. Systematic regional planning uses a Multi-Criteria Decision Analysis framework which provides an explicit structure for defining and analysing complex NRM decisions, quantifying the uncertainty involved in these decisions and making recommendations for actions. Systematic regional planning was conducted to set geographic priorities for the NRM actions of vegetation management, revegetation of local native species, and biomass production. SRP was conducted in order to quantify the minimum cost of reaching regional resource condition targets and to identify the geographic priorities for each NRM action.

In developing the concept of systematic regional planning for multiple objective natural resource management we add to existing resource condition targets. Enhanced objectives for vegetation management, revegetation and biomass production are developed based on systematic conservation planning principles, economic principles, and principles of integrated natural resource management. Implementation of the suite of principles in systematic regional planning involves the use of spatial optimisation techniques with the MCDA framework which identify geographic priorities for NRM actions that increase the likelihood that NRM actions will actually achieve the desired NRM goals.

The implementation of SRP in the Corridor involved several analyses in construction of the attribute layers for input into spatial optimisation in MCDA. These analyses had important policy implications themselves including the quantification of the influence of revegetation in river salinity mitigation as modelled over a 100 year time horizon and wind erosion mitigation, and confirmation of the economic viability of biomass production as a land use in the Corridor.

Systematic regional planning revealed that given the current levels of government funding, regional resource condition targets are unlikely to be met by either vegetation management or revegetation without private landholders bearing a significant portion of the cost. In costing the implementation of SRP principles in the Corridor it was found that the NRM issues of salinity and wind erosion could be addressed by vegetation management in addition to the biodiversity goals at minimal extra cost.

In planning for revegetation, we considered that the resource condition target of a 1% increase in vegetation was not likely to contribute to the NRM goal of conserving regional biodiversity, especially if the least expensive options were taken. Instead, we design and implement SRP based on a 15% representativeness target as a long term goal for revegetation. The amount of revegetation required to meet this target is about 4 times more expensive than the 1% target but the NRM benefits are likely to be substantially more. Including consideration of Landscape Context, Fragmentation status and Wind Erosion Potential in the model increased the likely NRM benefits from revegetation at some extra cost. Including the NRM benefits of revegetating all Salinity Benefit Areas (as modelled by SIMPACT over a 100 year time frame) and Long-Term Eroding Land was much more expensive.

Biomass production was found to be potentially viable in the Corridor and the most profitable sites could return a net present value of $24 Million more than existing land uses. Biomass production could also provide significant NRM benefits for salinity and wind erosion. The integration of a NRM credit system to encourage biomass plantings in high priority areas for salinity and wind erosion benefits is not likely to be cost effective.

Market-based policy mechanisms are suggested for encouraging vegetation management and revegetation of local native species to achieve biodiversity benefits. An invited tendering system is suggested which provides a spatially targeted approach to the distribution of funds for NRM. The tendering approach has been found to achieve greater efficiency in NRM actions than standard devolved grant schemes because of the substantial costs borne by the landholders. Multiple benefit NRM credit systems could also be implemented and possibly combined with the tendering system. Carbon credits especially have considerable potential for encouraging the large scale NRM actions required to meet the multiple objectives of salinity, biodiversity, wind erosion and additionally, carbon sequestration, in the Corridor. A biomass industry development program is also proposed. Industry development may involve market research and tendering of a biomass production contract aimed at utility and similar companies with experience in biomass industries. The successful company would manage all stages of the industry from production contracts to marketing biomass products.

In this study we have identified future options for most cost effectively addressing NRM targets in the South Australian River Murray Corridor. We have quantified the cost, feasibility and impacts of achieving a few selected resource condition targets and discussed policy instruments which may provide the greatest chance of meeting targets. Future directions for research include extending the concept of SRP, integrating climate change impacts, and designing policy that optimally encourages NRM actions in the priority locations identified by SRP.

10. Appendices

10.1. Appendix 1

The Resource Condition Targets for the SAMDB INRM Region (INRM Group 2003c)

1. Maintain and improve the extent and condition of 65% of current floodplain vegetation communities in areas of high priority by 2020
2. By 2020, a 30% reduction in priority areas of floodplain currently affected by salinity from groundwater discharge.
3. Maintain and improve the condition and connectedness of 60% of wetlands of high priority by 2020
4. Maintain and improve the condition of 60% of the littoral zone of high priority and high significance by 2020
5. By 2020, improve the habitat in all waters to permit successful recruitment of native fish, particularly Murray Cod, resulting from natural or manipulated flows.
6. Recover 30% of water dependent ecosystems from pest infestation and minimize any further infestations by 2020.
7. By 2020, to have salinity of water in the River Murray less than 800EC for 95% of the time at Morgan to ensure drinking water standards
8. By 2020, to have salinity of water in the River Murray less than 543EC for 80% of the time at Berri Irrigation Pump Station to ensure drinking water standards
9. By 2020, to have salinity of water in the River Murray less than 770EC for 80% of the time at Murray Bridge Pump Station to ensure drinking water standards
10. The phosphorous concentration in the River Murray is to be less than or equal to 0.05mg/L 90% of the time by 2020.
11. The nitrogen concentration in the River Murray is to be less than or equal to 1.0mg/L 90% of the time by 2020.
12. The turbidity level in the River Murray is to be equal or less than 80 NTU 90% of the time by 2020.
13. Maintain blue green algal levels below the national standard threshold level for all sections of the Murray river and the lower lakes by 2020
14. Maintain and improve the stability of river banks, lake edges, sand dunes and cliffs by 2020
15. The Murray mouth open 100% of the time through fresh water outflows with adequate tidal variation to meet the needs of Coorong ecosystems
16. 30% of flow maintained in watercourses of EMLR to sustain ecosystem function by 2020
17. By 2020 to have constrained the area of salt affected land within the region to 120,000 ha.
18. By 2020, reduce the area of agricultural land at risk of wind erosion during June each year by 40%.
19. Reduce recharge by improving dryland water use efficiency to 70% across the region by 2020
20. To have an increasing trend in Soil carbon levels in cropping soils leading to improved soil health by 2020
21. Recover 30 % of quality native vegetation, habitat and agricultural production areas from pest infestation and minimize any further infestations by 2020
22. By 2020 improve or maintain condition of terrestrial native vegetation focusing on identified priority areas and improve condition of 50% of remnant vegetation on private land as well as increasing vegetation cover by 1% in the agricultural region.

23. Maintain and improve the conservation status of all threatened National and State listed species and regionally threatened communities and species by 2020.
24. By 2020 groundwater resources will not have salinity impacts on land condition and will meet the needs of dependent ecosystems.
25. By 2006 to have developed a RCT relative to irrigated and waterlogged land
26. The *E.coli* count in the River Murray is to be less than or equal to 150 ec/100mL for 90% of the time by 2020.

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